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Towards a global performance indicator for losses from water supply systems

Eddy Renaud

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Author name and affiliation: **Eddy RENAUD**

Cemagref, France

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Contact person:

Eddy RENAUD

Cemagref Bordeaux

50 avenue de Verdun, Gazinet

33612 CESTAS Cedex France

Tel 05 57 89 08 33

E-Mail eddy.renaud@cemagref.fr

Context

Struggling against water losses in water supply systems is important for territories with problems in water resources. As a consequence the French legislative proposal concerning the national engagement for the environment stipulates the following disposition (République Française, 2009): “When the rate of water loss of a network is greater than the rate, fixed by the decree according to the characteristics of the service and of the resource, the public water supply and sanitation services establish, before the end of the second exercise following the exercise for which the excess was noted, an action plan containing, if it is arguable, a project of pluriannual program for works aimed at network improvement”

This disposition raises several questions, specifically:

- Which indicators are the most relevant to assess the water loss rate in a network?
- Which threshold values can be fixed and according to which network characteristics are those to be adjusted?

These questions are to be considered in a constrained context, since the rules are supposed to be applied to 14 000 various French water distribution services. Moreover, only a limited quantity of data is presently demanded by the French legislation from drinking water distribution services in the framework of the annual report on the prices and on the quality of the service (République Française, 2007).

The purpose of this article is to study the water loss indicators, currently used in France and internationally, as well as to envisage a global indicator which would potentially harmonise different approaches. This global indicator is supposed to be founded on minimal information and to allow a more comprehensive analysis when supplementary data are available. A case study is provided to illustrate this approach.

French indicators

The main performance indicator, recommended by the French legislation (République Française, 2007) to assess water losses in a drinking water supply network, is the Linear Leakage Index, defined as:

$$LLI = \frac{CAWL}{365 \times Lm}$$

LLI: Linear leakage Index, expressed in m³/km/day

CAWL: Current Annual Water Losses in m³; this volume comprises the real losses and the apparent losses, according to definitions proposed by the International Water Association (IWA) (Alegre et al., 2006).

Lm: The main's length in km.

A study accomplished by Cemagref for SMEGREG (a public structure in charge of water saving management in the Departement of Gironde in the South-West of France) showed a strong linear relation between the linear leakage index and the density of customers (expressed in customers per km of main). The impact of the length of mains on the level of losses was recognized negligible as compared to the impact of the number of customers. These results concerned rural or intermediate networks (Renaud , 2009).

This study led the SMEGREG to adopt a reference system of the linear leakage index adjusted proportionally to the customers' density. This actually implies using a new indicator, the Customer Leakage Index (CLI).

$$CLI = \frac{CAWL}{365 \times N}$$

CLI: Customer leakage index in m³/customer/day

CAWL: Current Annual Water Losses in m³

N: Number of customers.

The data from more than 2 000 French networks were used to establish the following references (Table 1) for networks with customer density less than 45 customers per km:

Low level of water losses	$CLI \leq 0.08$
Moderate level of water losses	$0.08 < CLI \leq 0.15$
High level of water losses	$0.15 < CLI \leq 0.29$
Very high level of water losses	$0.29 < CLI$

Table 1 CLI system of reference applicable to rural and intermediate networks

International indicators

The Infrastructure Leakage Index (*ILI*), is an IWA Performance Indicator (PI) for operational management of real losses (Alegre et al, 2006). It is widely used in many countries for ten years to assess the level of real losses in Water Supply Systems. *ILI* is the ratio of Current Annual Real Losses (*CARL*) to Unavoidable Annual Real Losses (*UARL*):

$$ILI = \frac{CARL}{UARL}$$

UARL is calculated using the following formula (Lambert et al, 1999):

$$UARL(\text{litres/day}) = (18 \times Lm + 0.8 \times Nc + 25 \times Lp) \times P$$

where *Lm* is the mains length (km), *Nc* is the number of service connections, *Lp* is the aggregate length of private pipes between property lines and customer meters (km), and *P* is the average pressure in metres.

Pressure Management is very efficient to reduce the leakage level of drinking water networks. However, *ILI* being the result of a ratio between two quantities which are proportional to pressure, the leakage reduction volume due to pressure management policies does not significantly influence the *ILI* value.

This fact leads S.W. Trow (Trow, 2009) to develop a new PI, the Pressure Management Index (*PMI*) as the ratio of the Current Average System Pressure (*CASP*) to Minimum Annual Reference Pressure (*MARP*):

$$PMI = \frac{CASP}{MARP}$$

CASP is *P* used in the *ILI* formula and *MARP* is related to the minimum standard of service:

$$PMI = \frac{P}{MARP}$$

S.W. Trow suggests using *ILI* and *PMI* together to monitor the progress in losses reduction both by Active Leakage Control and Pressure Management (Figure 1).

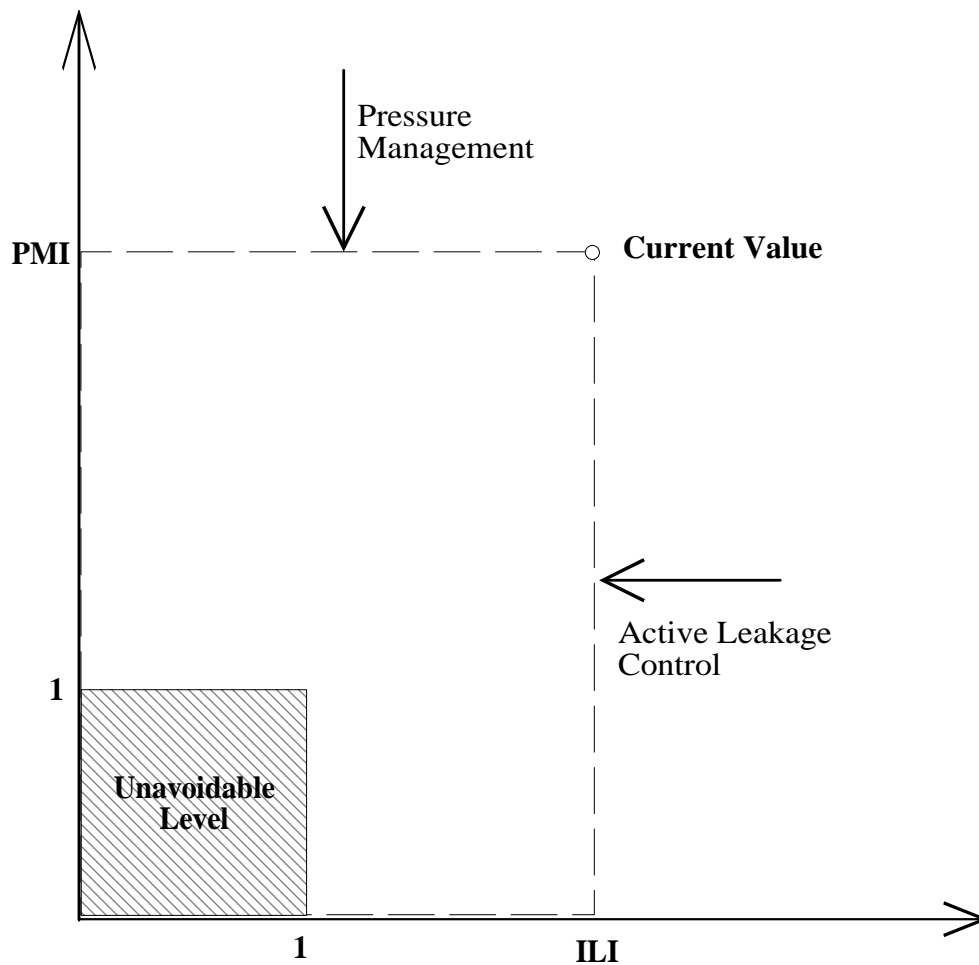


Figure 1 Combined use of *ILI* and *PMI* to assess water losses level

Global Leakage Index

In Figure 1, the area delimited by current values of *ILI* and *PMI* gives an indication of the potential water losses reduction according to the two ways of action. It leads us to consider the calculation of the delimited area's value and thus, to propose a new PI, the Global Leakage Index (*GLI*) which is the product of *ILI* and *PMI*:

$$GLI = ILI \times PMI$$

Let $UARL_i$ be the value of *UARL* for $P=i$, then

$UARL_1 = 18 \times Lm + 0.8 \times Nc + 25Lp$ and then $UARL = UARL_p = UARL_1 \times P$,

this gives $ILI = \frac{CARL}{UARL_1 \times P}$ and $PMI = \frac{P}{MARP}$, then

$$GLI = \frac{CARL}{UARL_1 \times P} \times \frac{P}{MARP}, \text{ giving } GLI = \frac{CARL}{UARL_1 \times MARP} \text{ or } GLI = \frac{CARL}{UARL_{MARP}}$$

Therefore, GLI is independent of P , the average pressure of the network. It is a very interesting property because in many cases, P is unknown. So, GLI can be a first level PI, easy to calculate, and which appears to be a useful tool for a large scale water losses benchmarking.

Evaluation of approximate value of GLI

In the framework of the already mentioned study that Cemagref had accomplished for the SMEGREG, we have shown that for rural networks, the length of mains does not have a significant effect on the level of losses when related to the number of customers. As a result, in average, the value of ILI increases with the customers density (D) and, for water supply systems with a low D , ILI is below 1 (Figure 2), which is impossible theoretically (Renaud et al, 2007).

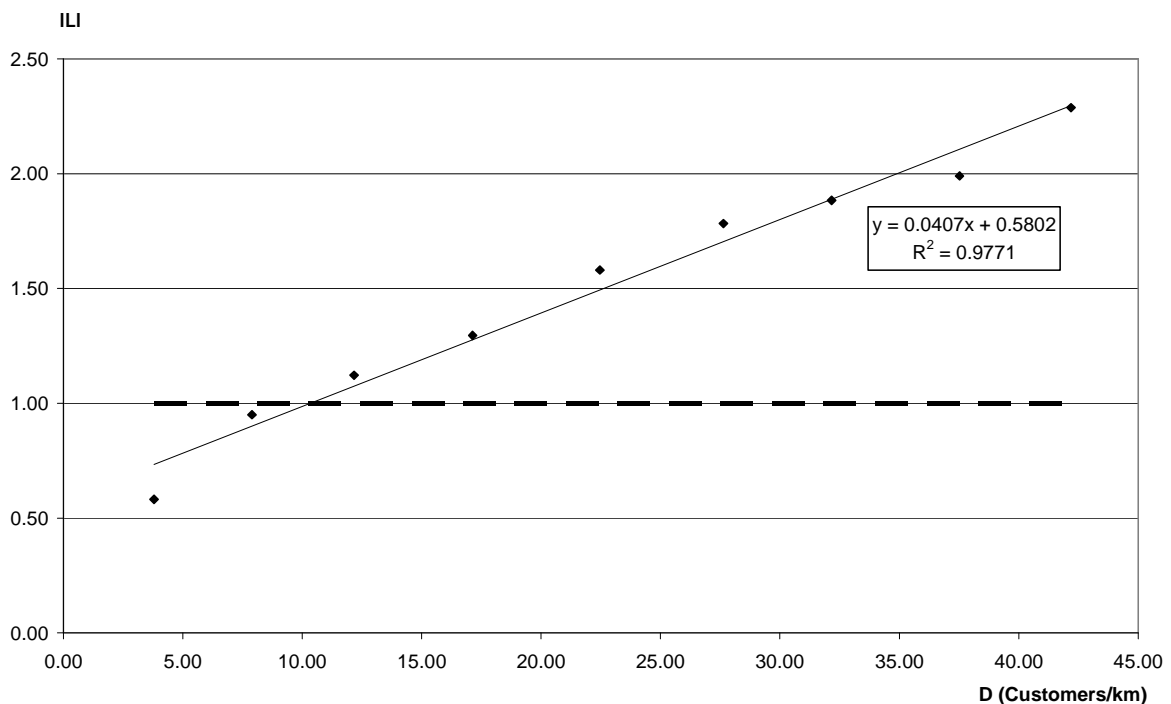


Figure 2 Variations of ILI according to the customers density

One hypothesis to explain this result is that D is positively correlated with such mains characteristics as diameter or age, and that, on the other hand, these characteristics have a significant effect on mains contribution to unavoidable losses. It amounts to assume that the “18” coefficient in the $UARL$ formula replaces a function of D . Cemagref currently carries out

studies to test this hypothesis. Henceforth, according to the data collected during 2003 – 2005 from 102 networks of Gironde (South-West of France), it can be stated that the customers' density increases with the increase in the average diameter of the network (Figure 3) and decreases with increasing proportion of PVC canalisations (Figure 4).

The average diameter for n pipes of a class is defined as $\overline{DIA} = \frac{\sum_{i=1}^n DIA_i \times L_i}{\sum_{i=1}^n L_i}$

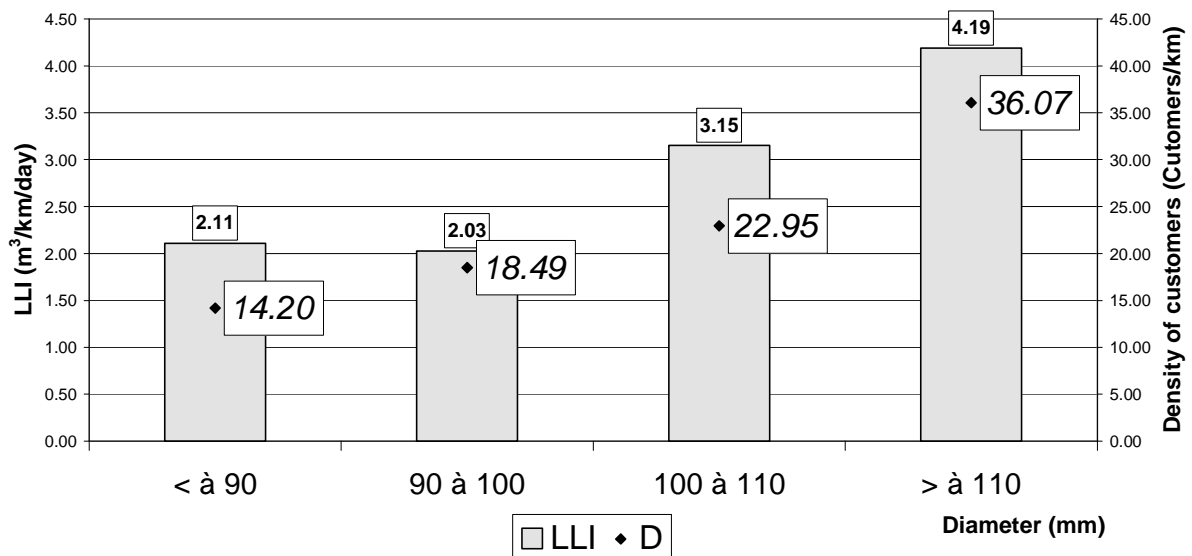


Figure 3 LLI and D according to average diameter

The average rate of PVC for n pipes of a class is defined as $\overline{R}_{PVC} = \frac{\sum_{i=1}^n PVC(i) \times L_i}{\sum_{i=1}^n L_i}$ where

$PVC(i)=1$ if pipe i is a PVC pipe and 0 otherwise.

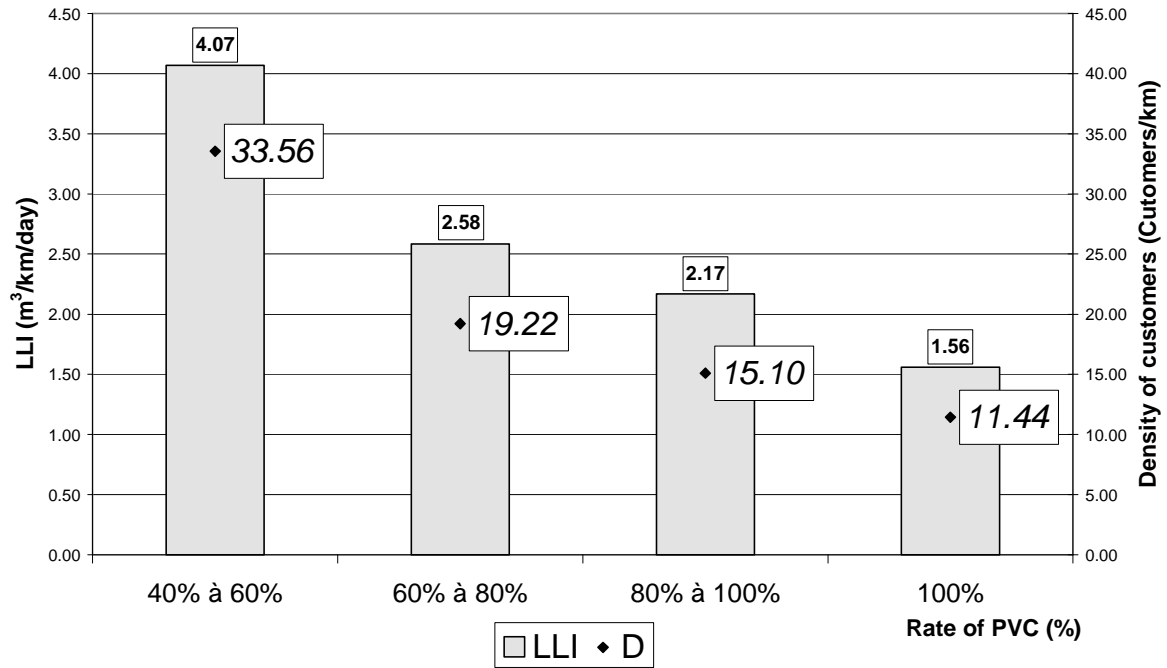


Figure 4 LLI and D according to average rate of PVC

At this stage, in order to take the preponderance of the number of customers (close to the number of connections for rural networks) into account when explaining the volume of losses, we propose an approximated estimate of $UARL$, $UARL^E$, calculated from average pressure and number of connections only:

$$UARL^E \text{ (litres / day)} = \left(\frac{18}{D_{ref}} \times Nc + 0.8 \times Nc + 25 \times lp_{ref} \times Nc \right) \times P \text{ then}$$

$$UARL^E \text{ (litres / day)} = \left(\frac{18}{D_{ref}} + 0.8 + 25 \times lp_{ref} \right) \times P \times Nc ,$$

where D_{ref} is the reference density of connections and lp_{ref} is the average length of private pipe between property lines and customer meter.

It is then possible to calculate in the same way an estimated value of GLI , GLI^E :

$$GLI^E = \frac{CARL}{UARL_{MARP}^E} \text{ with } UARL_{MARP}^E = \left(\frac{18}{D_{ref}} + 0.8 + 25 \times lp_{ref} \right) \times MARP \times Nc$$

GLI^E values for networks studied in 2007 have been calculated using the following reference values:

- $D_{ref} = 45$ connections/km ;
- $lp_{ref} = 0.008$ km/connection ;
- $MARP = 20$ m.

$$\text{Then } GLI^E = \frac{CARL(\text{litres / day})}{28 \times Nc}$$

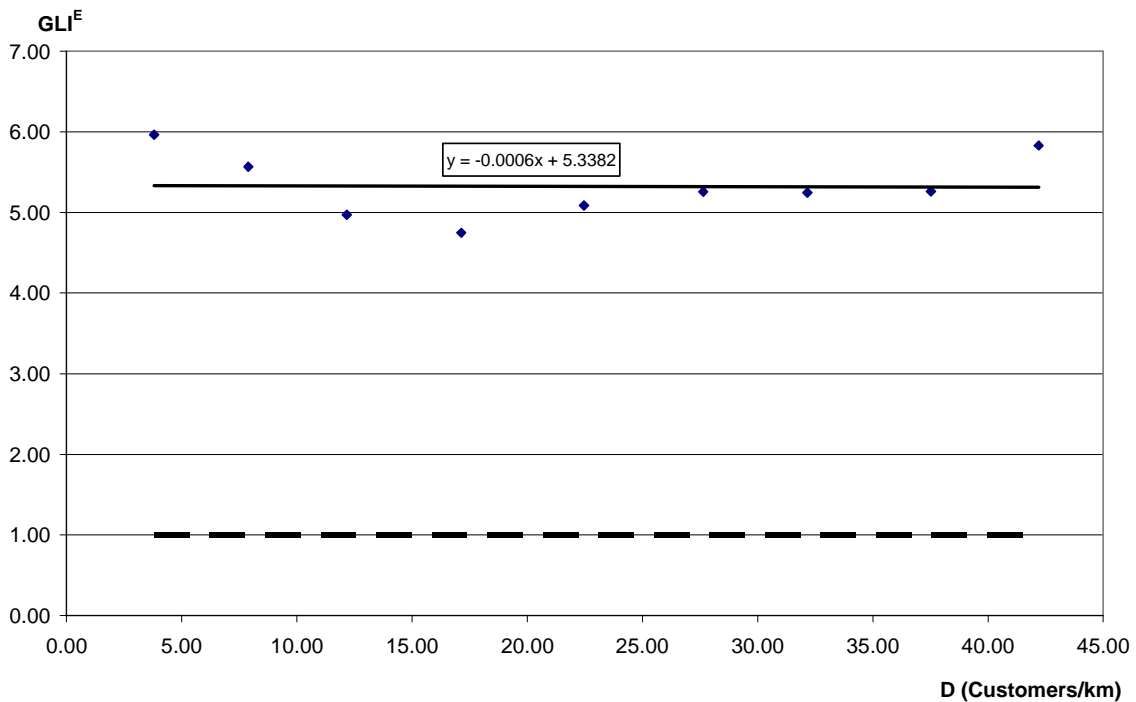


Figure 5 Variations of GLI^E according to customers' density

Contrarily to ILI , GLI^E is independent of D , the linear regression slope is close to zero (Figure 5).

Correspondence between GLI^E and the SMEGREG reference values.

For rural and intermediate French networks, the volume of apparent losses is generally small in respect to the real losses and the number of connections is often close to the number of customers:

$$CARL \approx CAWL \text{ and } N \approx N_c, \text{ then } GLI^E \approx \frac{CAWL(\text{litres/day})}{28 \times N}.$$

In this case, when $GLI^E = 1$, it is almost equivalent to $CLI = 0.03$.

The SMEGREG's reference can therefore be completed by a new threshold (Table 2), corresponding to the value of $UARL$ when $MARP=20$.

Very low level of water losses ($\leq UARL_{20}^E$)	$CLI \leq 0.03$
Low level of water losses	$0.03 < CLI \leq 0.08$
Moderate level of water losses	$0.08 < CLI \leq 0.15$
High level of water losses	$0.15 < CLI \leq 0.29$
Very high level of water losses	$0.29 < CLI$

Table 2 CLI system of reference including $UARL_{20}^E$ level (applicable when $D < 45$ customers/km)

Under the hypotheses stated above, a reference value equivalent to GLI^E can be derived (Table 3).

Very low level of water losses ($\leq \text{UARL}_{20}^E$)	$\text{GLI}^E \leq 1$
Low level of water losses	$1 < \text{GLI}^E \leq 3$
Moderate level of water losses	$3 < \text{GLI}^E \leq 5$
High level of water losses	$5 < \text{GLI}^E \leq 10$
Very high level of water losses	$10 < \text{GLI}^E$

Table 3 GLI^E system of reference (applicable when $D < 45$ customers/km)

Considering the equivalence between CLI and GLI^E , it is reasonable to doubt the interestingness of this second indicator.

The first, perhaps quite weak advantage, consists in providing the thresholds quite easy to memorize. The second advantage, less trivial, is that by definition, GLI^E allows more thorough analyses. Indeed, if estimation of the average pressure of a service is feasible, it is possible to calculate PMI_{20} (the PMI value for $\text{MARP} = 20$) and thus derive the ILI^E (an estimated value of ILI).

$$\text{ILI}^E = \frac{\text{GLI}^E}{\text{PMI}_{20}}$$

Firstly, this gives an idea about the respective interests of active leakage control and of pressure adjustment. Secondly, the evaluation of estimated values of IWA indicators facilitates international comparisons. All this can then invite the services, mostly concerned with water losses, to establish and implement good practices proclaimed by IWA to evaluate PMI and GLI.

Case study: application to a rural network

The Régie Municipale Multiservices de La Réole (RMMS) is a rural network of the South-West of France, having considerable losses, which decided to implement the action plan to struggle against it.

The network is divided into district metered areas (DMAs) (Figure 6).

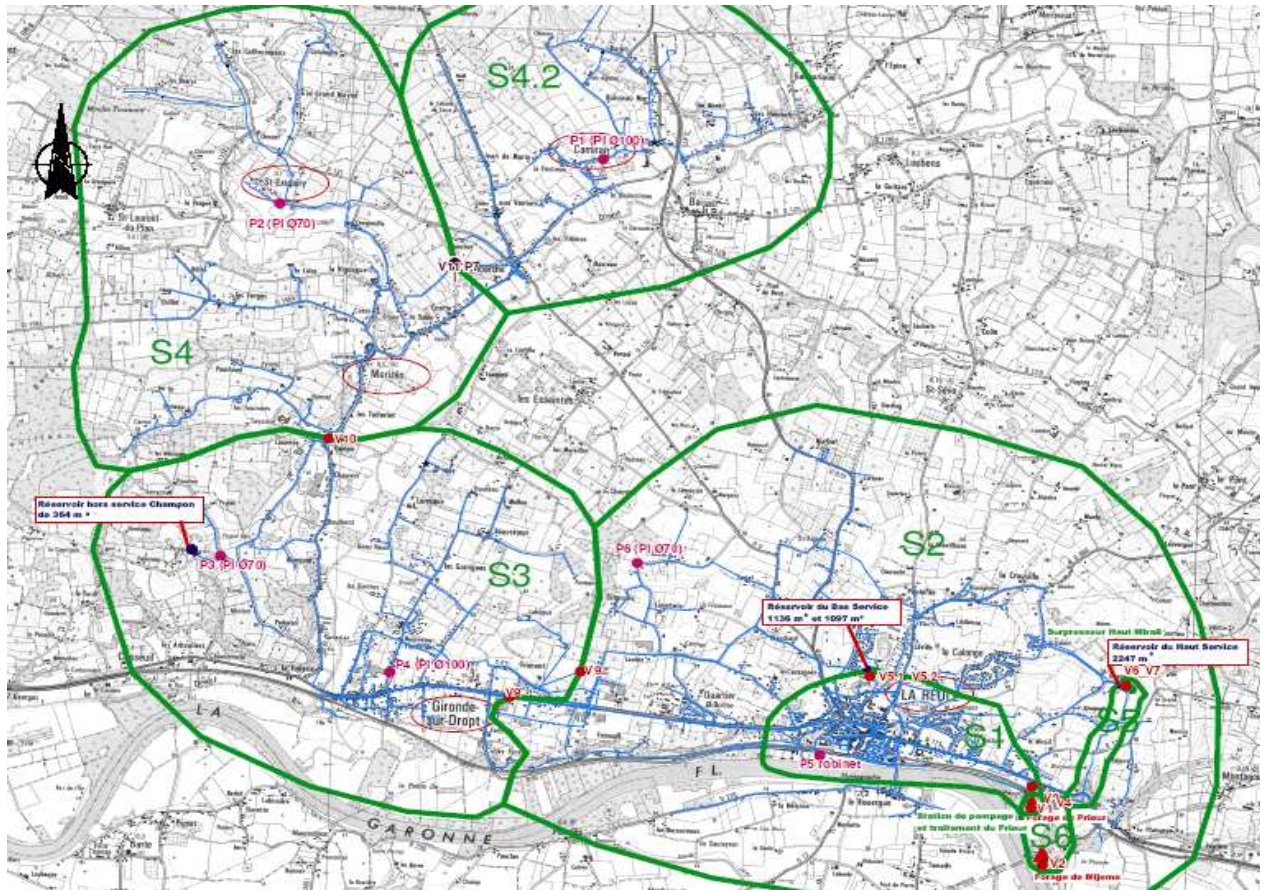


Figure 6 Map of DMAs of RMMS

Given the available information on annual consumption of users, PIs can be calculated over three zones (S1-2, S3, S4). The overall data and PIs are also presented (Table 4, Table 5).

	Number of connections	Length (km)	Average Pressure (m)	Annual supplied volume (m3)	Annual consumed volume (m3)
S1-2	2 451	77	54	385 000	242 000
S3	635	29	110	151 000	79 000
S4	557	35	104	167 000	52 000
Overall	3 643	141	80	703 000	373 000

Table 4 RMMS, data 2008

	D (connections/km)	CAWL (m3/year)	LLI	GLI ^E	PMI ₂₀	ILI ^E
S1-2	32	143 000	5.1	5.8	2.7	2.1
S3	22	72 000	6.8	11.3	5.5	2.1
S4	16	115 000	9.0	20.6	5.2	4.0
Overall	26	330 000	6.4	9.0	4.0	2.3

Table 5 RMMS, indicators 2008

Globally for the network, $GLI^E = 9.0$, which corresponds to high level of losses according to SMEGREG references. More detailed investigation of the GLI^E by zone uncovers the diversity of situations. The indicator appears to be useful in identifying the problem sectors.

The analysis is followed by calculation of PMI_{20} and ILI^E . Globally for the whole network $PMI_{20} = 4.0$ and $ILI^E = 2.3$, which indicates that pressure optimization is a more efficient direction of the performance improvement than active leakage control or assets rehabilitation. The investigation of values by zone shows that the potential of pressure reduction especially concerns S3 and S4 ($PMI_{20} > 5$) and that the S4 is a priority for an active leakage control.

This example illustrates the interest if using the GLI^E , which enables the identification of the most critical zones like the PI per connection and which additionally, allows to simply perform a more detailed analysis when the average pressure is available.

By means of the estimation of the average length of private pipes between property lines and customer meters, it is possible to calculate the value of UARL, then that of ILI for each zone (Table 6).

	L (km)	Nc	lp (km/Co)	Lp (km)	UARL ₁ (l/d)	P(m)	UARL (l/d)
S1-2	77	2451	0.005	12	3653	54	197 271
S3	29	635	0.015	10	1268	110	139 494
S4	35	557	0.015	8	1284	104	133 585
Overall	141	3643	0.008	30	6206	80	496 462

Table 6 RMMS, calculation of UARL

	UARL (l/d)	CARL (l/d)	ILI	ILI^E	ILI^E/ILI	D (Co/km)
S1-2	197 271	391 781	2	2.1	1.05	32
S3	139 494	197 260	1.4	2.1	1.50	22
S4	133 585	315 068	2.4	4.0	1.67	16
Overall	496 462	904 110	1.8	2.3	1.28	26

Table 7 RMMS, comparison between ILI and ILI^E

As expected considering the assumptions stated to allow the ILI^E 's calculation ($D_{ref} = 45$ connections/km and $L_{pref} = 0.008$ km/connection) for the low density studied network $ILI^E > ILI$, the less the density of a zone is, the more this difference is considerable (Table 7). As mentioned above, it has been shown that for rural and intermediates networks ILI is excessively weak in average and is difficult to interpret since it is correlated with the customers density. In forthcoming studies we envisage to test the sensitivity of ILI^E to assess its capacity to represent the performance, regardless the size or the configuration of the network.

Conclusion

GLI (Global Leakage Index) which is the product of ILI (Infrastructure Leakage Index) and PMI (Pressure Management Index) seems to be relevant to preliminary assess the level of losses of a water supply system, in particular while an evaluation of average pressure of the network is unavailable.

GLI^E, an approximated value of GLI, can be derived from only CARL (Current Annual Real Losses) and Nc (number of connections). This approach allows to connect international PIs with French reference values, based on the LLI (Linear Leakage Index) as function of the customer density or based on the CLI (Customer Leakage Index).

As it was shown by the case study, GLI^E's advantage is that it is easily calculated even by services disposing of few information. This PI is nevertheless useful in the first stage of a more involved analysis when data on pressure is available.

Future studies will concern the investigation of GLI in order to assess its relevance and to examine the interest of evaluation of the ILI's estimated value (ILI^E)

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