ESTIMATION OF NOT MEASURED WATER VOLUME SUPPLIED TO RESIDENTIAL CONSUMERS, IN JUAZEIRO – BAHIA

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Abstract: The presented paper describes a work developed in a 180 000 habitants city in the Northeast of Brazil, that intends to characterize the water consumption profile of typical residential consumers and estimate the volume not measured and billed, due to the inaccuracy of the water meters, function of the age of installation.
Keywords – water meters, calibration, consumption forecast.

1 INTRODUCTION

Turbine water meters, usually classified as *single* and *multijet* types, are extensively used in water volume consumer metering with billing purposes in the word. In Brazil these kind of meters are used in almost all residential installations. The model called *extra dry*, that has the gear reductor or totalizer kept in a sealed box with no contact with the water, is preferred, mainly because of the high level of particulate and sand that can be often found in the water, that can be damage volumetric rotary piston meters or even turbine meters where the gears work in contact with the measured water

These meters have a characteristic error curve as shown in figure 1. It can be noticed that the indication error at lower flowrates can be very high and negative, comparing to the error at higher flowrates. At these flow rates, the mechanic resistance (inertia, friction) is significative compared to the momentum generated by the action of the flowrate on the blades of the turbine and in an extreme, when the flow rate is so slow that cannot turn the turbine, the meter does not register any volume.

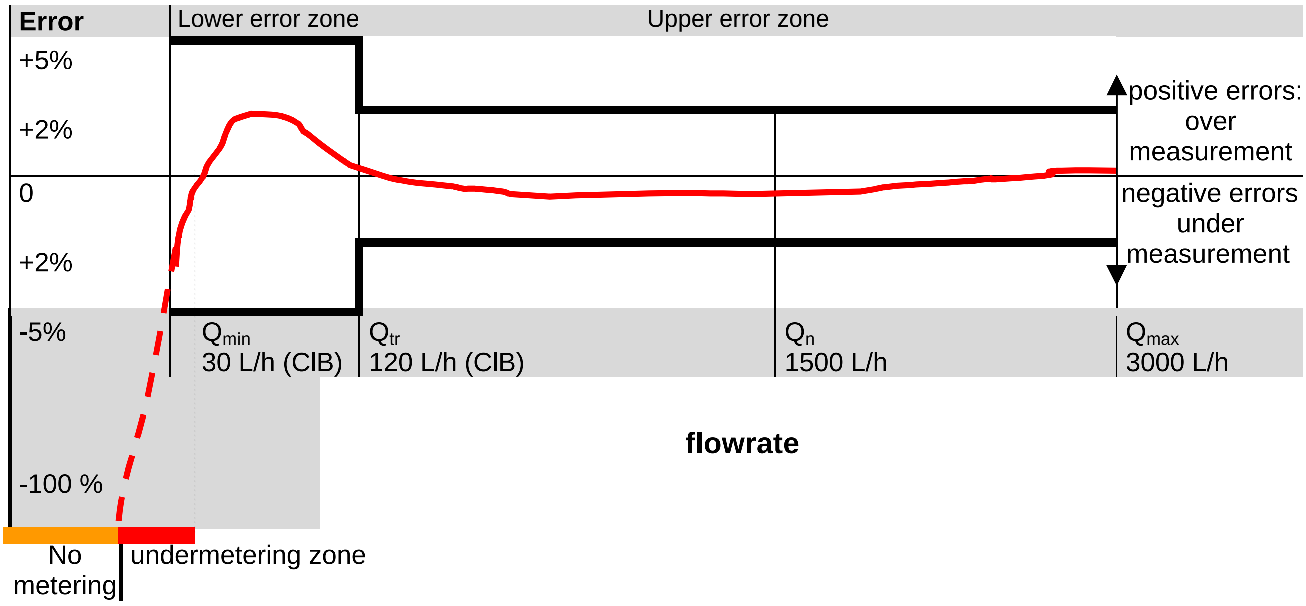

Figure 1. A typical error curve for a turbine water meter

It other words, it means that if the meter is working at lower flowrates, the indicated volume can be considerably inferior than the actual flown volume.

This unmetered, also called *undermetered* volume, is a water supplied to consumers and not billed and it is an important concern to any water distribution utility, specially in systems that work usually at low flowrates, as it is the case of many Brazilian residential installations that often use big water tanks at the top of the buildings.

Two ways are used to deal with this problem :

- use of meters with higher accuracy in low flowrates,
- estimation of the not measured water, based on the characteristic of the consumers and quantification of progressive lack of accuracy of the water meters installed in the system.

The use of high accuracy water meters (class “C” or “D”, according to ISO 4064 [1]) is easy but more expensive then use regular class “B” meters and does not solve the problem of lack of accuracy with the installation age, that, sometimes, can be even worse to high accuracy meters, that are usually more sensitive to the water quality and wear in the bearings of the turbine and gears.

The estimation of total unmeasured water volume, on the other hand, depends on the data available of the system that is intended to be studied. In a first approach, reference parameters and data from censitary surveys, other studies and even from studies in similar systems can be used, as well as information from laboratory studies of water meter long term performance [2] [3].

However, these data, when available, are often not adequate to the study, and it is often necessary to assume many hypothesis about the water consumption behaviour that makes the study questionable.

The purpose of this work is to estimate the global volume of water supplied to the costumers of a city and not measured and consequently, not billed, by a direct measurement of the actual water consumption profile and the measurement errors of the water meters that are installed in the system.

2 CARACHTERIZATION OF THE STUDIED CITY

The study were developed on the city of Juazeiro, Bahia, a city of almost 180 000 inhabitants, closed to São Francisco river and Sobradinho damp, in a region of intensive irrigated agriculture, with no remarkable highs and with a hot and dry weather most of the year. Juazeiro is a city mainly residential low population density, with few buildings with more than two floors. Local commerce and industry are mainly related with agricultural products. The water supplied to the city comes directly from the river and ot is considered with low turbidity.

This city were chosen by a Brazilian federal program (*PNCDA – National Program on Water Waste Control*) to develop a pilot project that includes evaluation of the Water Treatment and distribution system, technical and commercial roll review, evaluation of water loses and use of low flow domestic devices.

The water distribution system of the city presents many problems. Not all the city have regular supply of water (some peripheral districts have water in their taps only few hours a day). The roll of consumers and the register of monthly consumption shows many lacks and possible mistakes and are been reviewed in the moment of this work.

Although water meters were not present in all the residences of the city, most of central districts are almost completely metered. In some peripheral districts, where there is no direct metering, the consumer is billed by fixed taxes. As the consumption profile is commonly affected by the presence of the meter, and there is an intention of meter all the consumer in the future, this work covers only the metered districts.

3 METHODOLOGY

The work was divided in three parts :

- Determination of the measurement error of typical water meter that are used in the residential installations in the region, and the tendency of the error curve according to the time of installation;
- The evaluation of the actual consumption profile, that means, the volume that was consumed in each flowrate;
- The correlation of the error curves and the average volume that is consumed at each flowrate.

As it is almost impossible to determine the error of all the water meters installed in the area, as well as determine the water consumption profile in all consumers of the city, the work were made on samples chosen after an evaluation of the historic registers of water consumption and physic characteristics of the residential consumers of the city.

3.1 Water meters error curves

To make the study, a sample of water meters were choosen an removed from the system to be calibrated in laboratory, in order to determine the average error curve function of the installation time.

As the intermittence of water supply can affect the life of the meters and change the consumption profile, and the metered volume is strongly affected by the air in the pipelines [4], the samples were taken from neighbourhoods or districts were it is known that are always full of water. Chosen the places, the samples were selected by the kind of consumer, the historic monthly measured volume and a age of installation, in proportions as close as possible to the existing in the whole population. Meters that can be suspicious of damage, or that presented no register of consumption in the last months were also not considered.

In the case of the city of Juazeiro, the selection were easier, because almost the totality of the meters utilised came from only one manufacturer, and the buy of meters were made in well determined and regular intervals. It allows that the variety of models and types of meters to be not large in the system.

A sample of 100 meters was collected from consumers of city districts called *Coutry Club* and *Centenário,* that present a monthly consumption between 10 up to 50 m^3/month, divided in following groups according to the time of installation:

- New meters 10 meters
- Meters with less than 5 years of installation 40 meters
- Meters with 5 up to 10 years of installation 40 meters
- Meters with more than 10 years of installation 10 meters

Ten unused meters (new) collected from the company stock were also calibrated, to compare the loss of accuracy to older meters. The amount of meters with more than ten years of installation is small compared to the meters with less then ten years.

The meters were calibrated in 8 flowrates(10 for new meters) distributed on the flowrate working range, estimated from the consume profile determination , and it was determined also the starting below that there is no consumption register. Some older meters were also dismounted to verify the condition of the internal parts.

3.2 Water consumption profile determination

To determine the water consumption profile, a sample of 25 consumers were chosen by the historic consumption and adequate conditions to install a new volumetric class "C" meter with pulse emitter and connection to a portable data logger. Two kinds of installation, common in the city, were chosen, as shown in figure 2.

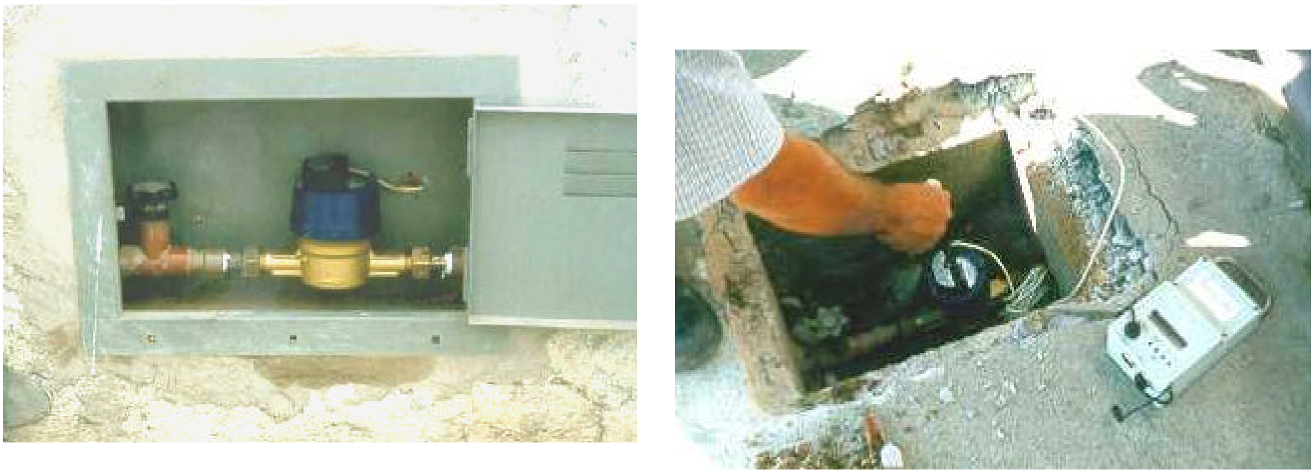

Figure 2 : Reference meters with pulse emitters an portable *data loggers* installed in residential consumers

The data logger were configured to register volumes of 0,1L, enough to make noticeable the utilisation of most domestic points of use of water (taps, lavatory, basins, showers) and, applying trace analysis techniques [5] [6], evaluate the use of the water in the residence.

The registration of data were made in fully weeks during the months of March to September of 1999, considering that there is no reason to have any difference in consumption in different weeks (it was avoid to collect data in weeks with holidays). Due to limitation in the available instruments (there were only there data loggers available) and problems with one consumer, it was possible collect data from 21 consumers o f the 25 formerly chosen. In the figure 3 can be seen the trace of a week of one the metered consumers.

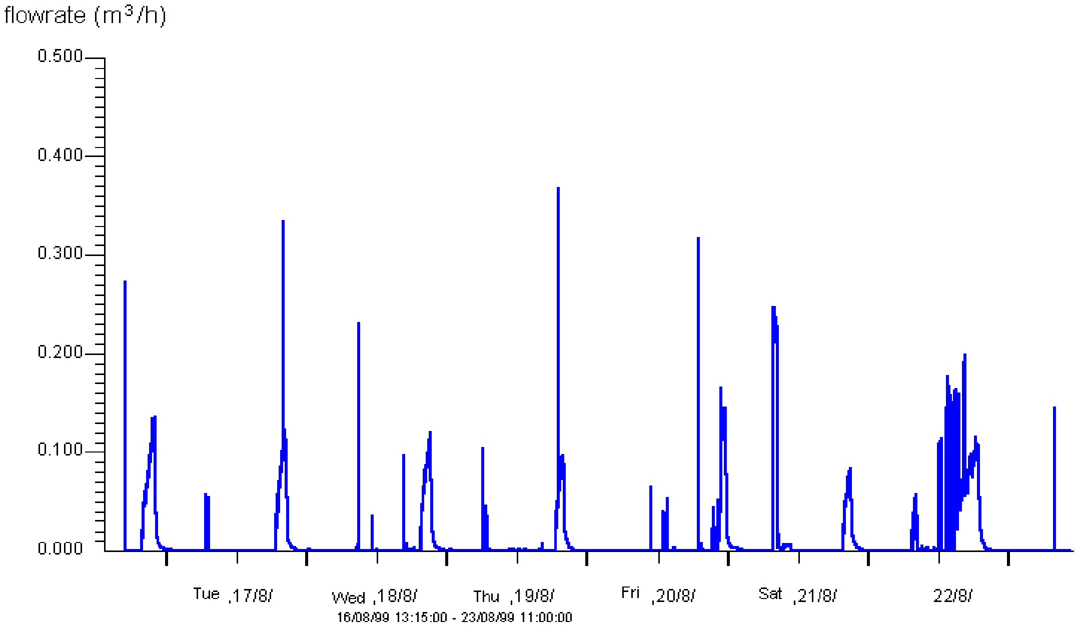

Figure 3 : Volume consumption trace of a typical residence in Juazeiro - Ba

Once collected, the data were manipulated by a statistical software in order to obtain diagrams of consumed water in function of the flowrate (also called consumption histograms), that were correlated with the error curves of the meters in order to establish the unmetered water. The histograms were determined for each studied consumer and all together, as a way to have an average picture of the consumption behaviour of the studied category. The reference meters used in the measurements were previously calibrated and the observed error were taken in account in the results.

3.3 Estimation of unmetered water consumption

To determine the unmetered water, the general histogram of the surveyed consumers was constructed in 11 to 13 bands of flowrates according to the significance of the volume measured. The first band, to flowrates from 0 to 20 L/h, for old meters and 0-12 for new meters, the meter were considered not working, and the whole volume as not measured. For the other bands, the volume not measured were obtained multiplying to the indication error at the flowrate equivalent to the middle of the band with the volume measured by the reference meter. The last band comprehends the measurement volumes that occurred over 850 L/h, and was correlated to the error observed at 1000 L/h.

The unmetered volume is the difference between the volume totalized by the reference meters and corrected by their indication error, and the sum of the volumes that would be measured for each band of flowrate, if the meter in the installation has an average behaviour for each category of installation time.

The unmetered volume can be also expressed in percentage, and, in this case, can be also called *unmetered water index*. If the district or the city has a roll of the meters classified by year of installation, an estimation of general *unmetered water index* can be obtained, applying the indexes to the amount of meters in each category, also taking in account, of course, an estimation of stopped meters by damage installed in regular consumers and that are to be substituted. These index can be also related to unbilled water, by correlating the results with the price of the water.

The *unmetered water index* is an important tool and its accuracy is very important because it indicates an amount of water that is really supplied to the consumer, despite it is not metered. An underevaluated index can wrongly indicate a high level of water loose and in the opposite, an overevaluted index can hide leaks and lost water.

4 RESULTS

In figure 4 are presented the average error curves for new meters and meters with 0 to 5, 5 to 10 an over 10 years of installation. The determinations were made with three repetitions, and the presented errors are the arithmetic average of all measurement. The indicated confidence interval represents the dispersion of two standard deviations for each point.

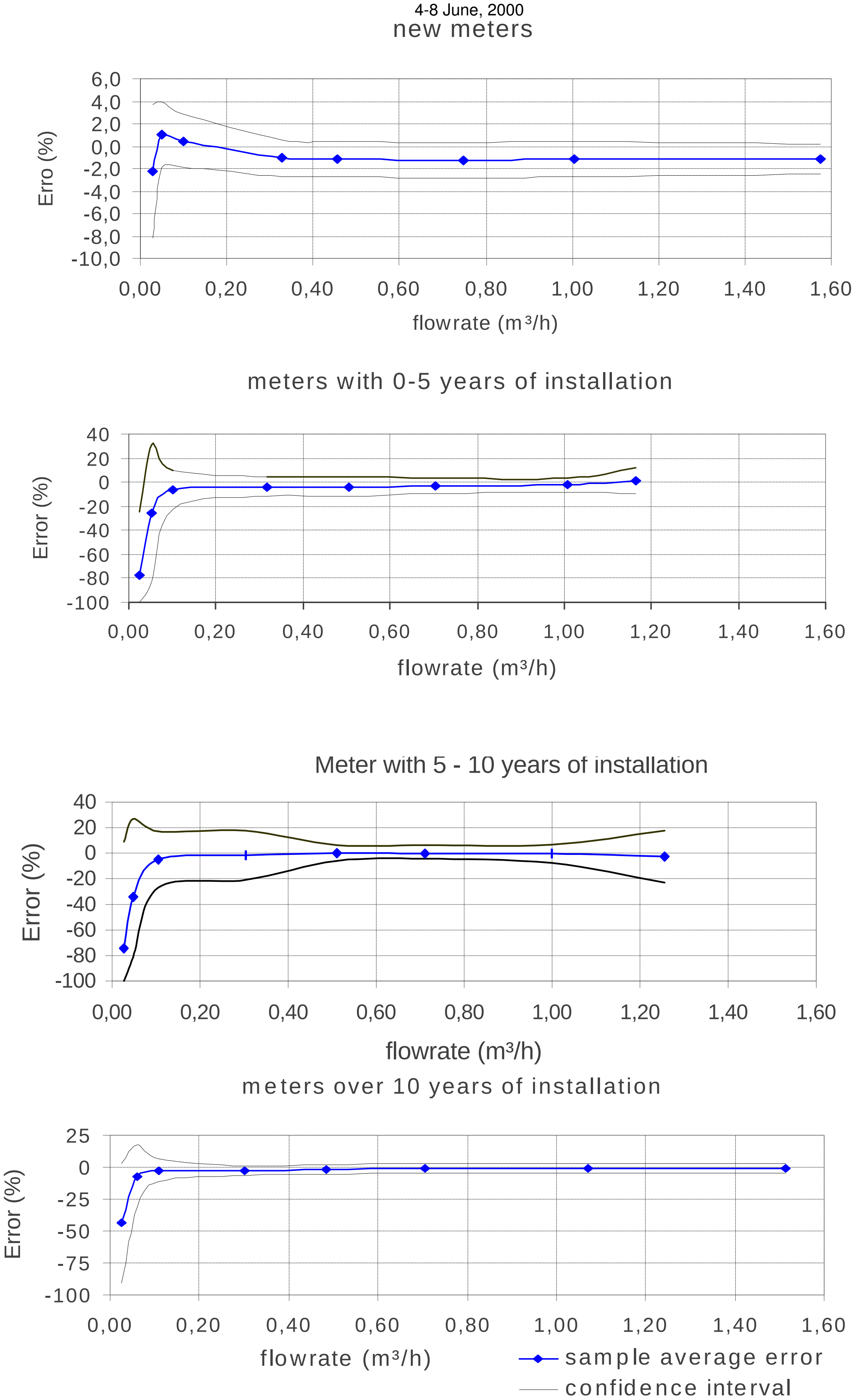

Figure 4 : sample error curves in function of time of installation

The lower observed dispersion in the meters with more than ten years of use, can be explained due to that meters that were clearly stopped or damaged were excluded from the survey and also by the fact that the distribution company priorizes the substitution of old damaged meters and the few old meters that still can be found n the installation are actually the best of their category.

In figure 5 is presented the histogram of the complete sample of surveyed consumers, divided in 26 categories of consumption, equally distributed in the whole meter range of work . In the figure 6 the same distribution is presented in a histogram divided only in 11 categories, based in the indication error observed in the meter calibration. The total volume measured considering all the surveyed consumer was close to 130 000 L.

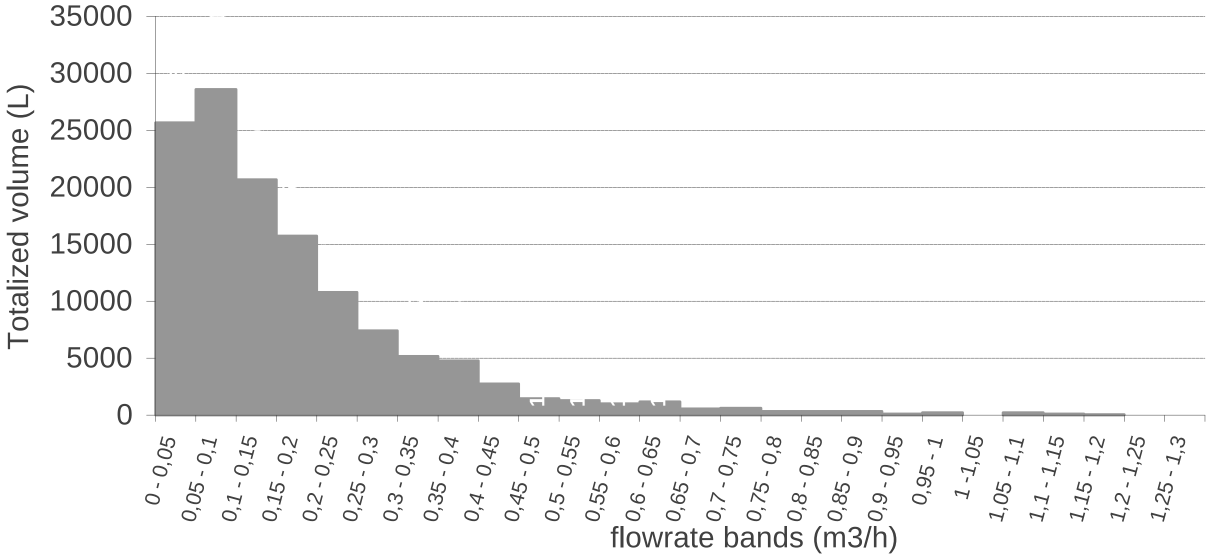

Figure 5 : Global consumption histogram for a sample of 21 consumers.

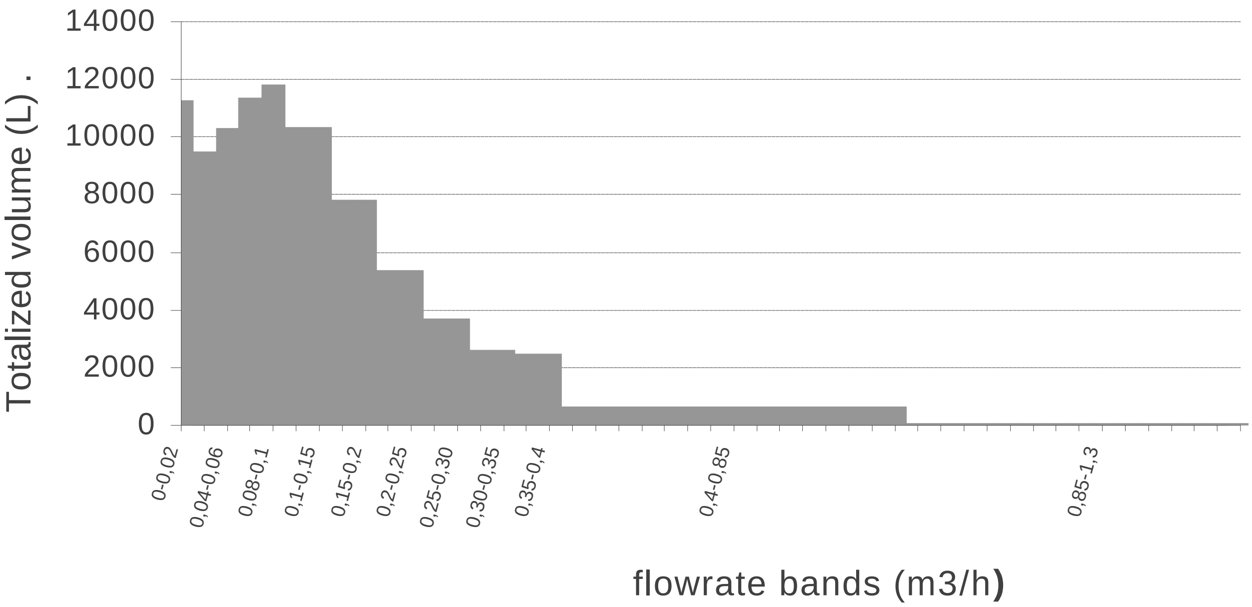

Figure 6 : Global consumption histogram for a sample of consumers, divided in 11 bands, according to the indication error of the meter.

For the not new meters, it was observed that almost all does not move in flowrates under 20 L/h and all the volume that was consumed up to this flowrate was considered not measured. For new meters it was observed 12 L/h as limit flowrate, under which there is no metering, and the first and second bands in the histogram of figure 6 are divided in three bands: 0-12 L/h, 12 to 25 L/h and 25-40 L/h.

In table 2 are presented the general calculations for the new meters, and In table 3 are presented the *unmetered water index* for each category of installation time.

Table 2 : calculations do determine the *unmetered water index* for new meters.

flowrate bands (L/h)	Volume mesured by reference meter (L)	reference meter error (%)	actual flown volume (L)	Volume mesured by the turbine meter (L)	Under metered volume (L)
0-12	8990.7	-100.0	9386.3	0.0	9386.3
12-25	4376.2	-20.3	4368.4	3483.3	885.2
25-40	7415.0	-0.92	7367.8	7299.8	68.0
40-60	10300.6	0.88	10192.9	10282.3	-89.4
60-80	11377.2	0.81	11259.9	11350.8	-90.8
80-100	11827.8	0.60	11707.6	11777.5	-69.9
100-150	20661.5	0.32	20437.0	20502.2	-65.3
150-200	15747.0	-0.02	15576.7	15573.5	3.2
200-250	10771.6	-0.36	10686.2	10647.7	38.5
250-300	7393.6	-0.70	7326.1	7274.7	51.3
300-350	5171.3	-1.04	5152.3	5098.7	53.6
350-400	4913.7	-1.08	4900.2	4847.2	53.0
400-850	9570.8	-1.23	9605.5	9487.8	117.7
850-1300	1140.8	-1.17	1150.4	1136.9	13.5
total	129657.8		129117.4		10355,1
				Index	7.98 %

Note: A negative under metered volume indicates that the turbine water meter tents to totalize a volume greater than the actual flown volume, due to a positive error of indication.

Table 3 : Unmetered water index by categories of installation time

Installation time (Years)	Unmetered water index (%)
New meters	8.0
0 to 5	14.8
5 to 10	22.4
over 10	13.9

5 CONCLUSIONS

The work demonstrate that the developed methodology is adequate to be use as a tool to estimate the water not metered due to the lack of accuracy of the meters used in a distribution system. The *Unmetered water index* obtained to studied city will be used as a base to review the global water loss index of the city, and would be applied in an study to choose a new water fare policy. The presented methodology is also been purposed as an standard method to be applied in other cities in Brazil and a brochure is been proposed to be published as an orientation.

From the calculations, it was noticed that for new meters, 90.6% (7.3% of the total metered water) of the unmetered water occurs at flowrates under 12 L/h, were the meter is considered stopped, and 95% of de undermeterd volume occurs at flowrates under the lower error limit of a class “B” meter, at 30 L/h. For older meters this percentage decreases, and for meters with 5 up to 10 years of installation, the undermetered volume under the starting flow considered of 20 L/h represents only 40% of the whole undermetered volume.

To calculate the *Unmetered water index* to the whole city or a district, the presented results can be extrapolated based on the proportion of meters of each category of installation time found in the target city or district, including the percentage of consumers with no individual metering or with a damage (stopped) meter. As the roll of consumers of the city of Juazeiro are old and it was found many differences, this determination will be made after a complete review of the roll, work that is now in execution.

As an example, if we suppose a proportion for the studied city of 10% of the installation with new meters, 40% with meters under 5 years, 30% from 5 up to 10 years, 10% over 10 years and 10% without meters or with damage meters, we can find a global *unmetered water index* of 24.8%.

It is important to remark that this index shows an estimation of water that is not metered, and that is not the same that the water not billed, because it is common to bill a minimum rate to a customer that does not present a metered consumption or a consumption under a specified volume. In the same way, to estimate the loss of income in monetary value, it is necessary apply the fare over the estimated actual consumption (the total consumption if all consumers were metered with zero error meters) and compare it with the actual income. This simulation is more difficult if we consider that usually the fare rate are not directly proportional to the consumed volume, but changes according to consumption ranges (the higher the consumption, the higher the rate).

Another important point is that the unmetered volume that occurs at flowrates were the meter does not indicate (it is stopped) is very significant , and its estimation is possible by the proposed method, that indicates that it is not necessary to use expensive high accuracy meters to have a good control of the unmetered water supplied. On the other hand, the importance of the volume of water not measured in the company income depends on the fare policy, and if it takes in account a realistic *unmetered water index*.

As a final comment, it can be observed that as this study was made over the maters and consumers that *actually* happen in part of the city, it is strongly advised that it will be extended by other districts that can have different characteristics (higher pressures, other brand of meters and poor quality water, as an example) and even repeated periodically as a way to have better quality indexes. It can be considered realistic even for Brazilian conditions, once the procedure can be considered not so difficult to be applied if adequate instruments are available. A large volume of data and information originated in similar studies executed in different cities and systems, can be an important tool in planing water forecast consumption and design distribution systems.

REFERENCES

[1] ISO 4064 - Measurement of liquid fluid flow in closed conduits - meters for cold potable water - Part. I & III - ISO 1983.

[2] EDWARDS, K., MARTIN, L. *A methodology for surveying domestic water consumption*. **Journal of the Chartered Institution of Water and Environmental Management**, V.9, n^{o} 5, p. 477 488, oct., 1995.

[3]BILLINGS, R. B., JONES, C. V. *Forecasting Urban Water Demand* **American Water and Works association,** Denver , USA 1996

[4]COSTA, A., SANCHEZ, J.G. et alli*, Análise de consumo e estimativa de perdas em sistema sujeito a intermitência no abastecimento* **Proceedings of the XX Congresso brasileiro de Engenharia Sanitária e Ambiental,** Rio de Janeiro, Brazil – 1999.

[5] SANCHEZ, J.G. *Dimensionamento de hidrômetros e análise de traço*. **Proceedings of XVIII Congresso Brasileiro de Engenharia Sanitária e Ambiental**, foz do Iguaçu, Brazil- 1997.

[6] De OREO, W.B. et alli *Flow trace annalysis to assess water use* **Journal of American Water and Works Association,** january 1996, p. 79-90, Denver USA 1996

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