Benchmarking of Leakage for Water Suppliers in Valle Del Cauca Region of Colombia

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Introduction

The geographic location, the diverse topography, and the climate that characterizes the Colombian territory have determined its abundance of water resources. However, water resources are not distributed homogeneously within the different regions of the country, putting them to strong variations that determine their availability; for this reason we find in the continental territory areas with shortage of water, and areas with excessive amount of water causing periodic flooding in important areas of the territory for long periods of time.

A major study on water balance and water supply and demand relationships was undertaken by The Colombian Institute of Hydrology, Meteorology and Environmental Studies–IDEAM, the results of which were published in the report ‘Estudio Nacional del Agua’ (IDEAM, 2000). The study includes: a water balance analysis for the entire country to determine regions where natural water deficit may occur, and various comparisons between water supply and water demand to identify regions where water availability may be scarce compared to demand and vulnerable regions for the years 2000, 2015 and 2025. The study was made considering average year and dry-year conditions of water supply (availability) and three spatial (area) categories: (a) for 45 basins and sub-basins covering the whole country; (b) for the areas corresponding to municipalities, and (c) for the areas that are sources of water supply for the municipalities.

IDEAM’s study also considered the effect of water quality that further restricts the availability of water supply. The study noted the serious water quality problem in most Colombian streams and rivers arising from a number of factors including: the lack of (water) treatment of municipal and industrial water discharges, the waste from mining activities, the substances brought from precipitation (e.g. acid rain), and the increasing amount of sediment resulting from the erosion caused by the expansion of agricultural and grazing livestock activities (particularly at high lands and mountains).

The results of the water balance analysis were formulated using the aridity index and the water supply and demand relationships were made using a scarcity index and a vulnerability measure. From the referred IDEAM’s report, the results for an average-year show that about 50% of the urban population might have water supply problems. While, for a dry-year conditions it would reach 80%. Consequently, if we do not employ adequate water management strategies, for the years 2015 and 2025, 66% and 69% (≈ 35 million inhabitants) respectively, of the total Colombian population for those years would be exposed to a high risk of supply shortage in dry-year conditions. Valle del Cauca is the department that could be the most affected area for these climatic conditions.

The Department of Valle del Cauca is located in the south west of Colombia and it is part of the Andean and Pacific regions. It has an area of 22140 km² and it is comprised of 42 municipalities, with a population of 4.5 million inhabitants (approximately), with 85% of them living in urban areas. (Fig.1)

In Colombia, like in other countries of the region, the evaluation of water losses in water supply systems is made by means of a percentage indicator called ‘Unaccounted-for Water-UfW’. According to Table 1 we can conclude that Colombia has not made significant progress in this field in the last few years. The performance indicator UfW for the first group of water utilities has been reduced by less than 1 point, from 40.3% in 1990 to 39.4% in 2001. And, for medium sized water utilities there was an increase from 42% in 1990 to 45.5% in 2001 (Fernandez, 2004).

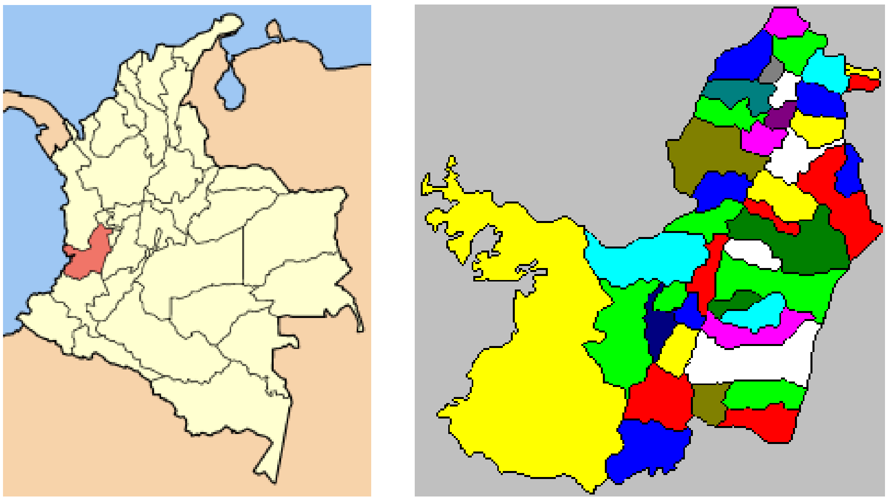

Figure 1.- Location of Valle del Cauca and its administrative division

These figures are in excess of the 20% established by the Water Drinking Systems Regulations-RAS 2000, and above the 30% established by Economic Regulator-CRA, as an indicator of the water utilities efficiency, which is included in the current tariff structure.

Table 1. Evolution of water losses in Colombia between 1990 - 2001 (Fernández, 2004)

UTILITY	1990		2001	
	UfW	m³/consm/m	UfW	m³/consm/m
> 500.000 served inhabitants	40.3%	23	39.4%	12
EAAB	42.2%	24	40.6%	13
EMCALI	43.9%	27	38.5%	16
EPM	38.1%	22	35.8%	11
AGUAS DE CARTAGENA	38.5%	25	49.2%	18
E.I.C.E. CÚCUTA	39.8%	20	49.6%	22
CIA DE AGUA DE B/MANGA	25.5%	12	30.2%	10
100.000 - 500.000 serv. inhab.	42.0%	23	45.5%	16
AGUAS DE PEREIRA	42.9%	29	41.6%	17
AGUAS DE MANIZALES	30.0%	14	33.2%	11
ARMENIA	51.2%	32	46.6%	15
NEIVA	45.4%	28	46.6%	24
POPAYAN	48.6%	29	48.2%	18
PROACTIVA	23.5%	8	61.3%	32
Total	40.6%	23	40.3%	13

It is very important to note that the difficulty in reducing this performance indicator is explained to great extent by the significant reduction that has occurred in the volume of water production, as a result of reduction in its consumption and, as a consequence of the increase in water rates and the expansion of coverage of customers metering; however, this indicator does not allow us to show the reduction in the volume of UfW that the utilities had to manage in order to keep the current levels of UfW.

Methodology of the Study

Motivation

Considering the high levels of water losses in water utilities in Colombia, and the 'dark' panorama of possible supply reduction that could hit the region of Valle del Cauca in the coming years, the Research Group in Advanced Urban Water Management (GIGAAU) has posed the question about the current levels of water losses in the region water utilities, but we found that every utility has its own definition for the percentage performance indicator UfW. This is in part because our Economic Regulator has defined only the main elements for calculating UfW PI (water volume produced and water volume billed) but not a component breakdown. On the other hand, several authors have stated (Lambert et al. 1999, Liemberger 2002) how inadequate the percentage indicators are for comparing losses among the utilities, regionally and internationally.

In consequence, the GIGAAU decided to undertake a benchmarking study of current levels of water losses in the water utilities of Valle del Cauca region.

Participating water suppliers

The following utilities participated in this initiative:

- Sociedad de Acueductos y Alcantarillados del Valle del Cauca- Acuavalle E.S.P
- Acuaviva S.A. E.S.P
- Aguas de Buga S.A. E.S.P
- Centro Aguas S.A. E.S.P
- Empresas Municipales de Cali. EMCALI - EICE - E.S.P
- Hidropacifico S.A. E.S.P

All the companies provided data for the year 2004. With the exception of Acuavalle E.S.P which is in charge of 33 water systems, the rest of the companies operate a single system. Within the participating utilities there are private and public companies and the systems vary widely in size, type, geographic location, operation and maintenance levels, this kind of variation was considered very important to demonstrate the applicability of the methodology to Colombian conditions.

Methodology

Presentation of the idea to the project participants, and a formal invitation to participate

All the candidate companies were invited to be part of the initiative of the GIGAAU research group. Participation was voluntary and it was free of charge for the utilities. Different alternatives were analyzed with companies regarding data confidentiality, and the conclusion was, that the final results will be presented in a synthetical manner using a numerical code that the GIGAAU will give exclusively to the company. This type of precaution generates some limitations with the interpretation of the results, because it does not allow the consideration of the contextual information, for example: the size and type of system.

Literature review

The literature review focused on several aspects: The compilation and analysis of the different current methodologies at national and international levels used to calculate the water balance; the identification and definition of performance indicators related to water losses in water distribution systems; and the study of the best practices for the reduction of water losses.

Definition of a methodology to calculate water balance and selection of performance indicators

From the information obtained in the literature review; finally, we adopted the terminology and methodology developed by IWA to calculate the water balance, and its performance indicators system. The IWA approach was selected for various reasons: first, it is intended for universal application; second, it allows the systems comparison at regional and international level; and finally, it was successfully used in more than 70 countries.

Visit to each of the participating companies

The GIGAAU team visited all the participating companies in the study with the purpose of having a closer look at the problems of each company in relation to water losses and their strategies for reducing them; additionally, the team introduced the IWA methodology to calculate the water balance and the performance indicators system to the staff in charge of leakage reduction.

Development of the data collection format

The GIGAAU designed a predetermined format in MS Excel to gather data, and sent it to all participants to enter all possible variables for calculating the water balance and the performance indicators. Additionally, a questionnaire was included to identify what kind of processes they are using in water losses reduction and practices for attention of failures and the conditions of water meters for the period 2002-2004 years.

Data reporting by participants

All participants submitted data for the year 2004 including system general information, the volume of water produced and authorized and non-authorized consumption. The Utilities were asked to submit only the information they had.

Data validation by GIGAAU, preliminary calculation of indicators and identification of inconsistencies

Once the GIGAAU received the data, the information was assessed analyzing the data consistency. For that purpose several mechanisms were used: Direct observation of the whole data, application of cross validation of data consistency, calculation of indicators, detection of anomalous values, and identification of parameters. This phase was more complex than how it was initially foreseen and very important for the rest of the process.

Request for clarification and data correction

Each participant received the corresponding comments to its data, with the identification of inconsistencies, and some missing information. In some particular cases, some clarification questions were asked. The answers were analyzed and processed.

A new calculation of performance indicators and issue of the draft version of the final report

With the new information, the water balance and the performance indicators were calculated for each system. Using this information, a statistical evaluation was done for each indicator and the preparation of a preliminary report that we sent to each one of the participants. Even after the correction and verification of the data some illogical data were found, which was associated with the data error. The participants were asked to analyze these situations, since this was the last chance for correcting wrong data before producing the final version of the report.

Presentation and discussion session with all participants in the study

The preliminary report constituted the core for the overall analysis of the results in a working session with all the participating water utilities and representatives of interested institutions and associations.

Elaboration of the final version of the report

After the working session and settling the questions, we proceed with the final version of the report.

Results

The study covered 40 water supply systems with different sizes, from 500 to 380.000 service connections. Out of the systems assessed 50% (20) are systems with less than 2500 service connections, 37% (15) are between 2500 and 12000 and the 13% (5) have more than 12000 service connections. For all the systems the connection density is between 24 and 197 connections per km of mains, with an average value of 113 (Table 2), very close to the maximum value of 114/km reported by Lambert et al. (1999).

Only 20% (4) of the systems of the first group reported values of average pressure; even though, the Regulator stipulates pressure monitoring at three points of the system twice a month when there are more than 1500 service connections in it. The pressure values in this group were between 38 and 15 m, with an average of 27.5 m. For the systems of the second group, the pressure values were between 19 and 43 m. with an average of 26.5 m. Only 40% reported the figures, even though the Regulator states that utilities have to check the pressure in 12 points of the system, 4 times a month. For the last group, the pressure values were between 40 and 23 m. with an average of 31.4 m.

The average volume of water injected into the system is: for the first group, 0.5 Mm^3/year; for the second group 2 Mm^3/year; and for the third group 11.5 Mm^3/year, with the exception of the largest company in the region with an input of 224 Mm^3/year. The average authorized consumption is 0.35 Mm^3/year; 1.4 Mm^3/year and 5.5 Mm^3/year, for groups 1, 2 and 3 respectively. The largest company has 134 Mm^3/year. The total average losses are 0.154 Mm^3/year for the first group; 0.73 Mm^3/year for the second group; and 6 millions for the third group; the total losses for the largest company are close to 90 Mm^3/year.

If we analyze the total losses as a percentage (Table 3), the average value of the whole sample is 33.3%, with values between 95.4% and 10.8%. Of this average value, 18.8% are real losses and the 14.5% are apparent losses. Now, if these losses are expressed by connection, we have an average value of 127.8 m^3/conn/year very close to the one reported by Alegre et al. (2005) of 130 for some European systems inside the CARE-W project. However, you can find some excessive values above 250 for the systems 34 and 39.

The apparent losses expressed per connection vary between 11.6 and 106.7 m^3/con/year, with an average value for the whole sample of 52.6 m^3/con/year or 144.2 l/con/day. The system 34 presents the biggest apparent losses of 292 l/con/day.

The real losses average is 259.8 l/con/day. This value is comparable with the average of the international data base of 276 l/con/day. However, when these losses are expressed in liters per km of mains per day, it comes to an average of 32.91 m^3/km/day, which is far from 12.55 m^3/km/day in the international data base.

Finally, and due to the restrictions to calculate the UARL (Lambert and McKenzie, 2002), we only got values of ILI for 9 systems (Figure 2), with an average of 8.7 with variations between 2.1 and 15.7 being comparable with the ones reported by Lambert and McKenzie (2002) of 7.4 for North American systems, and 6.0 for 26 South African systems. Nevertheless, it is far from the international average of 4.2 in the data base.

On the other hand the average value of UARL (Figure 3), is 27.1 liters per connection per day, lower than the value reported by Seago et al. (2004) as a norm of 50 liters per connection per day.

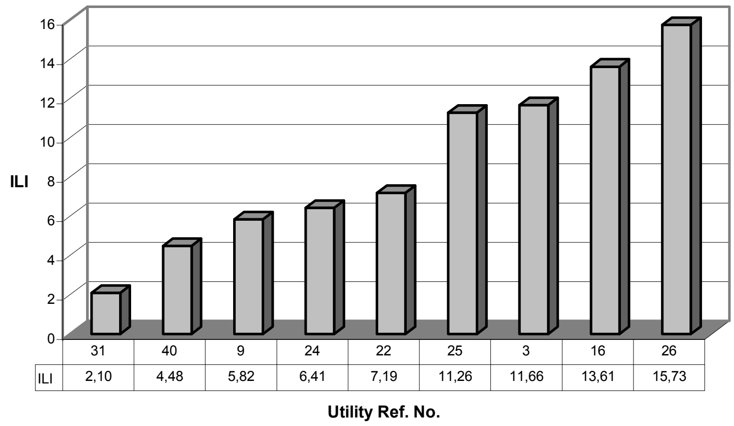

Figure 2: ILI values for Valle del Cauca systems

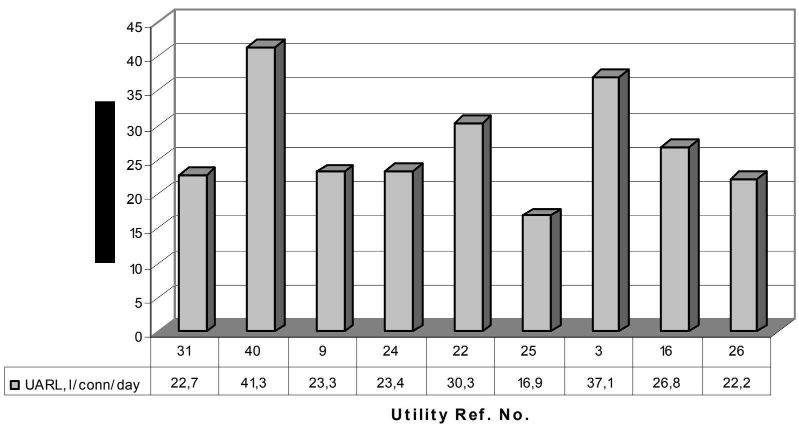

Figure 3: UARL values for Valle del Cauca systems

Problems Experienced

As previously mentioned, we requested information about the system's characteristics and volume of water produced and consumed from the companies and all the practices used in water loss reduction. In each one we found certain problems.

One of the aspects to highlight is the lack of integrated information systems within the company's structure; the figures of produced water are handled by the technical staff, whereas the figures of water consumption are the commercial office responsibility, which is in charge of the meter readings and billing. Thus each one of these departments produces and stores its data, with a minimal sharing of information with other departments.

The methods used to measure the water produced vary extensively from Parshall flume to ultrasonic and electromagnetic meters. However, the companies do not have reliable information about metering errors of these devices. They are hardly ever calibrated, some of these devices have installation problems and when they are damaged, they are not repaired for a long time. We could say that the reliability of these devices is not first priority for these companies, because the regulator does not have any policy at all on this matter.

The apparent losses were not reported by the participants because of the lack of management of water meters. None of the companies has information about the measuring errors for those devices. Additionally, some of the companies have an important number of customers with stopped meters and meters with more than 10 years of use without being replaced.

Something similar happens with the theft of water, and illegal connections. There are complete areas in some cities that have not been included as active customers, most of the time due to political pressures on public water utilities.

Another aspect related to apparent losses is errors in the transmission of consumption data to the office in charge of billing. This is critical, especially in small systems that are supported by a central office with lack of field controls. To calculate the apparent losses we implemented the Seago et al. (2004) methodology applied in South African conditions, considered to be very close to our circumstances.

Based on this, the recommendation of working on the water balance with the 95% confidence limits could not be implemented in this stage of the study, due to lack of knowledge of the implicit errors in measuring and the refusal of people in charge to estimate the implicit degree of error in their estimations.

On the other hand, the number of service connections is an unknown quantity for the companies; they usually have no information on this respect. All the companies report the number of customers but not the number of connections. The alternative of using the number of properties was not feasible because utilities did not have this information. In consequence, for systems with no information about the number of service connections it was supposed that, the number of connections is equal to the number of customers.

The customers' meters in our cities are located close to the edge of the street and the property boundary so the private underground pipe between street/property boundary and customer meter was considered equal to zero in this study, $L_p=0$.

The information about practices for water loss reduction used by utilities was practically nonexistent, none of them carried out an active leakage control. The zoning of the systems has just started. Only two companies are managing pressures. The records of repairs say too little about their causes and the time used for attendance and repairs. Finally, the information about water meters is so poor that it practically does not allow one to make any inference about metering aspects.

Conclusions

The application of IWA approach for water balance and performance indicators has proven to be adequate for the Colombian conditions. Even though, we met some difficulties that entail unreliable results. This study, which is the first trial of application of IWA methodology in Colombia, has shown the great constraints that we have with information management systems and comprehension of water losses components and their modelling for the development of NRW reduction strategies.

In Colombia, water losses control is based on intuitive aspects rather than technical ones; nevertheless, the application results of IWA methodology shows an acceptable performance in Valle del Cauca utilities and in some cases comparable with International standards, but it is evident that in a large number of systems, improvements have to be made.

Table 2: Valle del Cauca System Data

Utility Ref. #	Length mains km	# Service Conn	Density conn/km	Average Pressure m	System input volume m³/year	Authorised consumption m³/year	Continuity days/year
Group 1- small < 2500 service connections							
35	16,57	511	31	-	237.963	135.924	365
18	5,02	593	118	-	144.916	115.601	365
38	5,85	668	114	-	203.777	124.066	365
12	5,01	691	138	-	180.382	160.860	365
1	9,09	767	84	-	171.095	129.164	365
39	44,91	1.081	24	-	630.994	342.326	365
36	27,88	1.166	42	-	378.632	232.811	365
5	12,53	1.213	97	-	417.984	293.955	365
2	25,32	1.251	49	-	380.374	292.383	365
14	14,71	1.436	98	-	530.232	345.973	365
6	11,12	1.565	141	24,9	391.477	304.761	365
30	17,76	1.749	99	-	676.099	529.762	365
20	12,41	1.864	150	-	554.530	411.455	365
33	15,76	2.002	127	-	660.921	486.340	365
27	14,90	2.035	137	32,5	619.292	490.476	365
11	11,09	2.182	197	15,0	595.121	489.712	365
4	26,73	2.247	84	37,8	1.083.043	532.654	365
19	37,21	2.316	62	-	724.736	554.563	365
10	43,21	2.367	55	-	936.066	622.925	365
Gr. Ave.	*18,79*	*1.458,11*	*97,17*	*27,55*	*500.928,18*	*347.142,65*	*365*
Group 2-medium 2500 to 12000 service connections							
7	25,16	2.565	102	24,2	763.365	609.939	365
23	38,57	2.587	67	-	889.149	574.337	365
15	31,60	3.053	97	-	1.264.224	835.971	365
32	22,62	3.731	165	-	1.443.286	1.087.379	365
8	30,70	3.940	128	-	1.345.527	620.627	365
37	72,00	3.940	55	-	1.497.628	1.062.979	365
21	59,20	5.437	92	-	2.936.181	1.579.420	365
24	48,95	5.834	119	24,6	1.959.468	1.366.780	365
9	48,05	5.903	123	24,6	2.015.131	1.435.830	365
40	59,11	6.365	108	42,7	2.327.651	1.581.489	365
17	56,02	6.470	115	-	3.226.756	1.970.533	365
31	50,23	6.640	132	24,3	2.574.732	2.049.247	365
25	45,34	7.918	175	18,7	2.327.314	1.481.469	365
13	55,74	8.296	149	-	3.912.221	2.288.950	365
28	55,55	9.013	162	-	3.945.216	2.927.519	365
Gr. Ave.	*46,59*	*5.446*	*119,2*	*26,52*	*2.161.857*	*1.431.498*	*365,00*
Group 3- Large > 12000 service connections							
22	120,00	14.956	125	32,1	6.282.905	4.244.776	365
16	131,72	25.031	190	30,0	13.944.591	8.485.879	365
34	199,80	39.329	197	-	10.726.632	489.712	60
26	337,93	40.069	119	23,4	14.930.208	8.611.173	365
3	2.642,06	382.150	145	40,1	223.925.097	134.155.690	365
Gr. Ave.	*686,30*	*100.307*	*154,94*	*31,39*	*53.961.887*	*31.197.446*	*304*
Smp Ave	115,06	15.665	113	28,20	7.993.716	4.719.369	357

Table 3. Valle del Cauca Water losses and Performance Indicators

Utility Ref. #	Total Losses m³/year	Apparent losses m³/year	Real Losses m³/year	Total Losses %Vinput	Op 23 Total Losses m³/conn/year	WR1 Real Losses % Vinput	Fi 46 Apparent losses % Vinput	Op 25 Apparent losses m³/conn/year	Op 27 Real Losses l/conn/day	Op 28 Real Losses l/km/day	Real Losses l/conn/day/m
Gruop 1- small < 2500 service connections											
35	102.039	28.544	73.494	42,9	199,7	30,9	12,0	55,9	394	12.149	-
18	29.314	24.276	5.038	20,2	49,4	3,5	16,8	40,9	23	2.748	-
38	79.711	26.054	53.657	39,1	119,3	26,3	12,8	39,0	220	25.151	-
12	19.522	8.043	11.479	10,8	28,3	6,4	4,5	11,6	46	6.278	-
1	41.931	27.124	14.807	24,5	54,7	8,7	15,9	35,4	53	4.463	-
39	288.668	71.888	216.779	45,7	267,0	34,4	11,4	66,5	549	13.224	-
36	145.822	48.890	96.932	38,5	125,1	25,6	12,9	41,9	228	9.524	-
5	124.029	61.731	62.299	29,7	102,2	14,9	14,8	50,9	141	13.622	-
2	87.992	61.400	26.591	23,1	70,3	7,0	16,1	49,1	58	2.877	-
14	184.259	72.654	111.605	34,8	128,3	21,0	13,7	50,6	213	20.781	-
6	86.716	64.000	22.716	22,2	55,4	5,8	16,3	40,9	40	5.598	1,6
30	146.337	111.250	35.087	21,6	83,7	5,2	16,5	63,6	55	5.414	-
20	143.076	86.405	56.670	25,8	76,8	10,2	15,6	46,4	83	12.512	-
33	174.581	102.131	72.449	26,4	87,2	11,0	15,5	51,0	99	12.593	-
27	128.816	103.000	25.816	20,8	63,3	4,2	16,6	50,6	35	4.748	1,1
11	105.409	102.840	2.569	17,7	48,3	0,4	17,3	47,1	3	635	0,2
4	550.389	111.857	438.532	50,8	244,9	40,5	10,3	49,8	535	44.950	14,1
19	170.173	116.458	53.715	23,5	73,5	7,4	16,1	50,3	64	3.955	-
10	313.142	130.814	182.327	33,5	132,3	19,5	14,0	55,3	211	11.561	-
Gr. Ave.	*153.786*	*71.545*	*82.240*	*29,03*	*105,78*	*14,88*	*14,15*	*47,20*	*160,49*	*11.199*	*4,26*
Group 2-medium 2500 to 12000 service connections											
7	153.426	128.087	25.339	20,1	59,8	3,3	16,8	49,9	27	2.760	1,1
23	314.812	120.611	194.202	35,4	121,7	21,8	13,6	46,6	206	13.793	-
15	428.252	175.554	252.698	33,9	140,3	20,0	13,9	57,5	227	21.912	-
32	355.907	228.350	127.557	24,7	95,4	8,8	15,8	61,2	94	15.448	-
8	724.900	130.332	594.568	53,9	184,0	44,2	9,7	33,1	413	53.058	-
37	434.649	223.226	211.423	29,0	110,3	14,1	14,9	56,7	147	8.045	-
21	1.356.762	331.678	1.025.084	46,2	249,5	34,9	11,3	61,0	517	47.439	-
24	592.689	273.356	319.333	30,2	101,6	16,3	14,0	46,9	150	17.873	6,1
9	579.301	287.166	292.135	28,7	98,1	14,5	14,3	48,6	136	16.656	5,5
40	746.161	316.298	429.864	32,1	117,2	18,5	13,6	49,7	185	19.925	4,3
17	1.256.223	413.812	842.411	38,9	194,2	26,1	12,8	64,0	357	41.196	-
31	525.485	409.849	115.636	20,4	79,1	4,5	15,9	61,7	48	6.307	2,0
25	845.846	296.294	549.552	36,3	106,8	23,6	12,7	37,4	190	33.207	10,2
13	1.623.271	480.680	1.142.592	41,5	195,7	29,2	12,3	57,9	377	56.162	-
28	1.017.697	614.779	402.918	25,8	112,9	10,2	15,6	68,2	122	19.870	-
Gr. Ave.	*730.359*	*295.338*	*435.021*	*33,14*	*131,11*	*19,34*	*13,80*	*53,36*	*213,01*	*24.910*	*4,87*
Group 3- Large > 12000 service connections											
22	2.038.129	848.955	1.189.174	32,4	136,3	18,9	13,5	56,8	218	27.149	6,8
16	5.458.712	2.121.470	3.337.242	39,1	218,1	23,9	15,2	84,8	365	69.413	12,2
34	10.236.920	4.197.137	6.039.783	95,4	260,3	56,3	39,1	106,7	2.524	496.919	-
26	6.319.035	1.205.564	5.113.471	42,3	157,7	34,2	8,1	30,1	350	41.457	15,0
3	89.769.407	29.514.252	60.255.155	40,1	234,9	26,9	13,2	77,2	432	62.482	10,8
Gr. Ave.	*22.764.440*	*7.577.476*	*15.186.965*	*49,89*	*201,45*	*32,06*	*17,82*	*71,11*	*777,84*	*139.484*	*11,18*
Smp Ave	3.274.346	1.119.918	2.154.428	33,29	127,79	18,80	14,49	52,63	259,84	32.919	6,49

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References

Alegre, H., Figuereido, R., and Duarte, P. (2005) Iniciativa PI-COMP: comparação de desempenho entre entidades gestoras de sistemas de abastecimento de água -Síntese de resultados. LECN, Departamento de Hidráulica e Ambiente.

IDEAM. (2000) Estudio Nacional del Agua, Ministerio del Medio Ambiente. Instituto de Hidrología, Meteorología y Estudios Ambientales, Colombia.

Fernández, D. (2004). REDI Informe final: Sector de Agua y Saneamiento. Consultant's report, The World Bank, Washington D.C.

Lambert, A., Brown, T.G., Takizawa, M., Weimer D. (1999) A Review of Performance Indicators for Real Losses from Water Supply Systems. AQUA, **48** (6).

Lambert, A., McKenzie, R. (2002) Practical Experience in Using the Infrastructure Leakage Index. Proc. of IWA Managing Leakage Conference, Cyprus.

Liemberger, R. (2002) Do you know how misleading the use of wrong performance indicator can be?. Proc. of IWA Managing Leakage Conference, Cyprus.

Seago, C., Bhagwan, J. and McKenzie, R. (2004) Benchmarking leakage from water reticulation systems in South Africa. Proc. of WISA Biennial Conference, Cape Town, South Africa.