CHARACTERISTICS OF LEAKAGE IN MARIBOR WATERWORKS, SLOVENIA

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Maribor, situated on the eastern part of Slovenia, is the second largest city in the country. Maribor has some aspects of city; a beautiful old city shown as the photograph, the biggest industrial city in the country, and good residential city surrounded green farm and rich forest.

Maribor has population of nearly 170,000 in 2000, including its small satellite cities. Maribor Waterworks, established in 1901, supplying these all cities with potable water, is the largest water supply company in the country. 19 million cubic meters of water is pumped from eight pumping stations in 2000. On the other hand, sold water is 12 million cubic meters. It is estimated that approximately 7 million cubic meters of the pumped water (approximately 36%) is lost by leakage from the underground pipe. There has been a large economic loss due to the leakage, and the leakage may influence a stable water supply in the near future. Furthermore, the

government of Slovenia issued a recommendation in 1996 that asks all waterworks should reduce leakage. According to the recommendation, Maribor Waterworks should achieve leakage ratio of 25 %.
Therefore the Municipality of Maribor requested a technical cooperation to the Japan International Cooperation Agency (JICA), which had carried out other cooperation about wastewater treatment in Maribor before. JICA sent two experts in succession from 2000 to 2003. A project team including JICA, Maribor Waterworks and Municipality of Maribor carried out a study to look for optimum measures of leakage reduction. This report summarizes the result of the study.

Is the leakage really much?

The title is my first question in Maribor Waterworks. Actually, the leakage ratio was nearly 40%, although the engineering level and the management quality seem not low compared with those of other developed countries. The question was resolved soon by introducing the definition of "Leakage amount per pipe length".
This rate shows how much water is leaking per one day per one kilometer of distribution pipe in certain area, and it is usually used in leakage detection works. Only "Leakage ratio" is generally used for representing leakage situation, however "Leakage amount per pipe length" is also important as a technical index.
At the same time, I suggested to divide the whole supply area into three blocks in order to grasp detailed data, and calculated those rates in each block as Table 1 shows. The bottom shows a situation of Fukuoka Waterworks I belong.

Table 1 Leakage data in blocks (2000)

	Distribution (1000m3/year)	Leakage amount (1000m3/year)	Pipe length (km)	Leakage ratio (%)	Leakage amount Per pipe length
Block 1	15,862	5,911	597	37.27	27.13
Block 2	1,140	344	48	30.18	19.48
Block 3	2,092	625	433	29.87	3.95
Total	19,094	6,880	1,079	36.03	17.47
Fukuoka	145,135	2,821	3,538	1.94	2.18

Calculated leakage amount per pipe length is about 17m3/day/km on the average, and I may say that the actual leakage is not so much in the whole supply area of Maribor Waterworks in spite of its high leakage ratio from the technical point of view.
Furthermore, regarding Block 3 that has approximately 40 % of distribution pipe in the supply area of Maribor Waterworks, the leakage amount per pipe length is as small as that of Fukuoka Waterworks whose leakage ratio is less than 2 %, considered as one of the best in Japan. However the leakage ratio in Block 3 is calculated as nearly 30 %.
Why such a phenomenon takes place? The relation between "Leakage ratio" and "Leakage amount per pipe length" is indicated as following formula (Other non-revenue amount except leakage amount is neglected here).

$$R_L = 100 * Q_L / (Q_L + A_C / L_P)$$

R_L = Leakage ratio (%)
Q_L = Leakage amount per pipe length (m3/day/km)
A_C = Consumption (m3/day)
L_P = Pipe length (km)

A_C / L_P in this formula can be regarded as "Efficiency of distribution pipe". And if this index is small, "leakage ratio" becomes bigger, and vice versa, under same leakage situation. That is to say, in sparsely populated cities compared with those distribution pipe length such as satellite cities of Maribor, the leakage ratio becomes bigger even if actual leakage is small. However, the fact only makes works difficult. That is to say, total cost of leakage prevention work should be reflected to leakage amount per pipe length directly, not to leakage ratio, and it is generally difficult to reduce small leakage amount further.

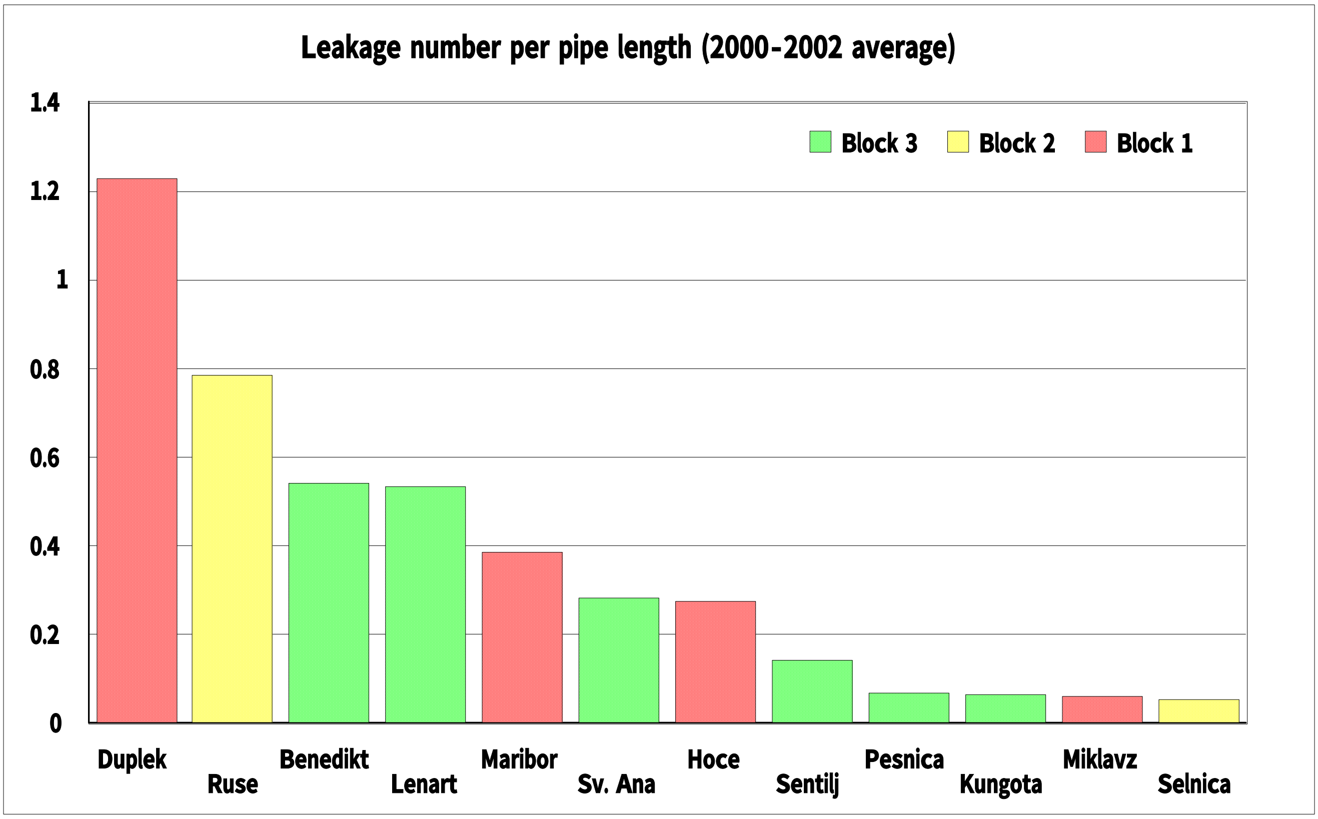
Analysis of leakage

Necessary measures to reduce leakage are "Leakage detection", "Improvement of pipe system (Pipe replacement)" and "Optimizing water pressure (Water pressure control)". These measures do not need special technology at present, however they need long time and enough cost. Therefore it is important to find most effective measures in each area of pipe network. That is, "Analysis of leakage" is important.

Minimum unit of analysis is 12 cities, since there are no data on smaller areas. Regarding distributed amount, data on each city are not exact, so that leakage amount in each city is uncertain. Although data of water pressure are important, there are few pressure gauges in the supply area. Reliable data are leakage cases number on each pipe material and each city for about ten years.

Graph 1 shows "Leakage number per pipe length" in each city, which shows how many times leakage occurs in 1 km of distribution pipe a year. As the graph shows, situation of leakage is quite different among cities. The frequency of leakage in the worst city is more than twenty times bigger than that in the best city.

Graph 1



It is also necessary to study on pipe materials and yearly change of data. Table 2 shows time series of leakage number on PEHD (Polyethylene pipe) and PVC (Polyvinyl chloride pipe), which mainly cause leakage. Although there still remains old CI (Cast iron pipe) that was laid nearly 100 years ago, almost of leakage cases occur from those about 20-year old plastic pipes.

Table 2 Leakage number on pipe material

Leakage Number on Pipe Material **PEHD** Leakage number includes detected leakage from 2000 to 2002
Pipe length in 2002, Number per km on average from 2000 to 2002

Municipality	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	P.length	N/km
Maribor	100	98	116	78	128	92	102	67	106	117	138	181.1	0.66
Miklavz	0	1	1	1	3	0	1	1	1	1	0	24.84	0.03
Hoce-Slivnica	0	6	1	2	1	2	6	13	8	10	13	19.24	0.54
Pesnica	1	2	3	1	3	5	1	4	1	3	8	118.17	0.03
Ruse	13	19	18	3	18	22	23	23	10	22	21	13.01	1.36
Selnica	1	0	3	9	6	8	2	1	0	1	0	6.49	0.05
Lenart	6	6	13	10	14	13	18	28	43	53	36	73.18	0.60
Benedikt	0	0	0	0	0	0	0	3	1	0	0	16.08	0.02
Sv.Ana	0	1	2	0	1	0	1	0	2	0	2	25.77	0.05
Sentilj	4	5	8	7	6	3	7	5	11	10	8	94.45	0.10
Duplek	7	3	9	7	12	14	16	29	32	43	81	33.84	1.54
Kungota	0	0	1	1	1	0	0	1	2	1	1	63.77	0.02
Total	132	141	175	119	193	159	177	175	217	261	308	669.94	0.39

Leakage Number on Pipe Material **PVC** Leakage number includes detected leakage from 2000 to 2002
Pipe length in 2002, Number per km on average from 2000 to 2002

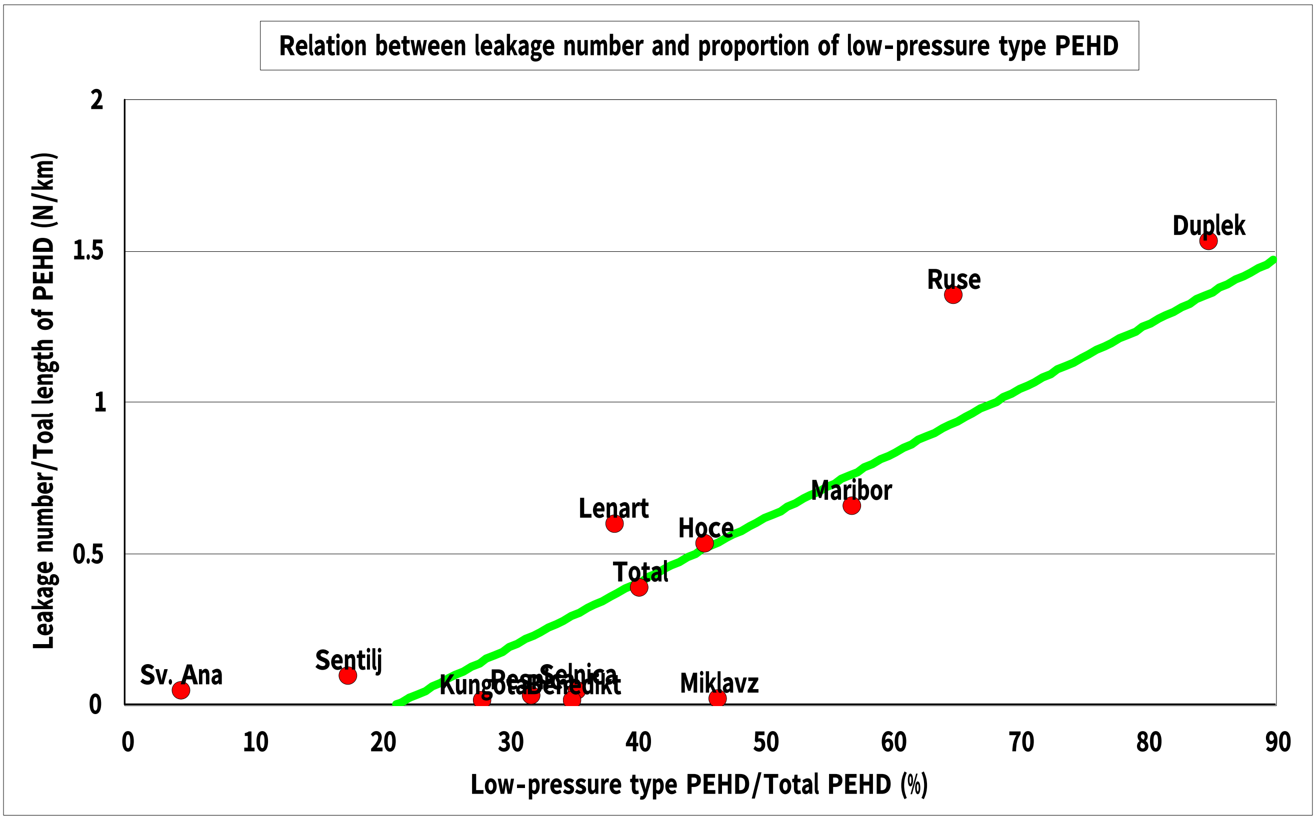
Municipality	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	P.length	N/km
Maribor	21	24	17	15	10	11	11	16	17	15	27	34.67	0.57
Miklavz	5	0	3	0	0	0	1	0	1	2	1	3.55	0.38
Hoce-Slivnica	2	0	0	1	1	1	4	0	0	0	0	3.28	0.00
Pesnica	6	1	4	0	1	3	5	7	3	3	7	8.33	0.52
Ruse	0	0	0	1	3	1	7	4	6	1	5	2.23	1.79
Selnica	0	0	0	0	0	0	1	0	0	0	0	0.91	0.00
Lenart	0	2	3	3	0	0	0	2	5	6	3	2.93	1.59
Benedikt	0	1	2	3	2	0	3	7	4	15	13	4.06	2.63
Sv.Ana	5	7	9	8	10	11	12	9	8	6	6	0.77	8.66
Sentilj	0	1	1	0	0	0	1	2	2	0	3	11.29	0.15
Duplek	0	0	1	1	1	0	2	1	1	1	0	1.59	0.42
Kungota	0	2	4	5	2	1	3	2	1	5	5	9.53	0.38
Total	39	38	44	37	30	28	50	50	48	54	70	83.14	0.69

The average of “Leakage number per pipe length” in the whole supply area is 0.33, and it is 0.39 on PEHD, 0.69 on PVC, while 0.15 on CI. These rates are shown in right column in Table 2. To say simply, it is most effective to conduct some measures on pipe in cities whose rate is bigger.

The question now arises that there are two categories of PEHD; low-pressure type and high-pressure type, and they were not classified on the mapping system. High-pressure type PEHD was adopted in place of low-pressure type PEHD in 1985. Although it is estimated that almost of leakage on PEHD occur from low-pressure type PEHD, there is no evidence.

Maribor Waterworks has grasped length of low-pressure type PEHD, and new data on leakage are being classified into two categories at present, however past data are still uncertain. Graph 2 shows the relation between leakage number and proportion of low-pressure type PEHD. The graph must prove that low-pressure type PEHD mainly causes leakage in some cities.

Graph 2



At the same time, however, the graph indexes another controversial phenomenon. That is, there are some cities whose leakage from PEHD is very little in spite of their long low-pressure type PEHD. The reason is estimated differences of water pressure condition, although actual water pressure cannot be measured. The situation is almost same about PVC, another critical pipe material.

Some of staffs in Maribor Waterworks have guessed unnecessary high water pressure or water hammer has caused leakage in certain areas of their network. Their experienced knowledge has corresponded with the graph. That is, the graph also shows an importance of water pressure control.

A relation between leakage and water pressure is generally shown as following formula.

$$Q = (P/P_0)^{\eta} * Q_0$$

Q : Reduced leakage amount
P : Lowered water pressure
Q_0 : Original leakage amount
P_0 : Original water pressure
η : Experienced index

Regarding the index η, if a leakage is considered as a orifice in open-air, η must be 0.5. And if it is regarded as permeation flow, η is nearly 1. However the index we have gotten in Fukuoka Waterworks is 1.88. That is to say, the influence of water pressure against leakage is much bigger than considered before. The reason why η is so big is considered that most of leakage occurs in crack and joint, furthermore new leakage always happens and a probability of leakage grows under higher pressure.

There must be considerable number of water hammer occurring because of the pump-up supply system, although modern pump system has been introduced and well managed. However actual situation is uncertain due to lack of monitoring equipment. Detailed studies are needed about relations between leakage and water pressure in order to determine what method is suitable in each area of the network.

Seeking optimum measures for each area in the network

A fundamental method to reduce leakage is "Leakage detection", however leakage cannot be reduced only with "Leakage detection". There must be many areas in the network where "Pipe replacement" or "Water pressure control" is more useful rather than "Leakage detection".

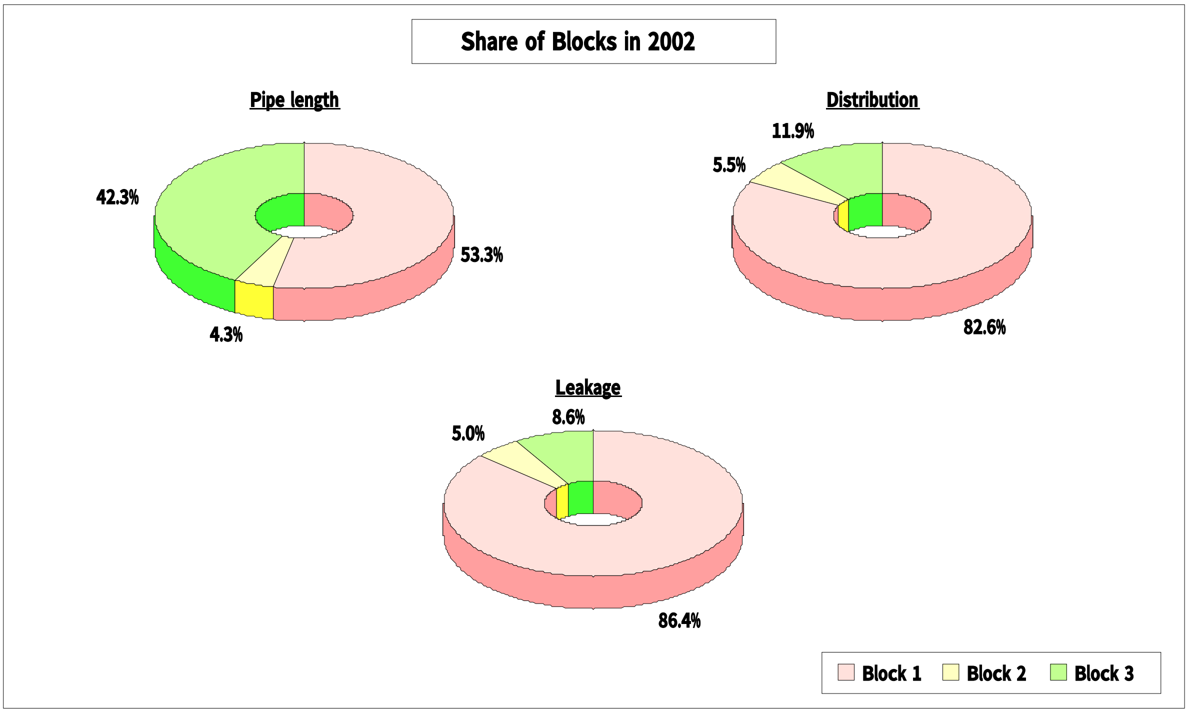
However an aim of "Leakage detection" is not only to find leakage, but also to collect data of the network. Therefore it is desirable to conduct leakage detection works in every area of the network at least once.

Maribor Waterworks have begun new "systematic" leakage detection works since the beginning of 2003 with their original work program in addition to the existent detection group. It will take five years to complete their works in whole network.

On the other hand, it is more effective to concentrate leakage detection works into Block 1 in order to reduce the leakage ratio of the whole network quickly.

Graph 3 shows share of each block in pipe length, distributed amount and leakage amount as pie charts. Block 1 has a majority in each item, however the proportion of the pipe length is approximately a half, while the leakage amount is nearly 90 % of total amount.

Graph 3



Regarding “Pipe replacement”, I have studied a priority. Maribor Waterworks has been conducting pipe replacement works vigorously on the basis of experimental decision. However future plan depending on objective analysis is necessary.
Although there are not enough data, the time series data of leakage number on each pipe material in each city have indexed the priority. Table 3 shows the pipe length that should be replaced in an early chance. These pipes cause leakage frequently compared with others, or the frequency of leakage is increasing year by year.
Total length of such pipes is more than 200 km, which might be too big compared with the present replacement pace of about 20 km/year. However it is necessary to complete replacement of these pipes, even if it takes about ten years.
The important point to note is that Block 1 has nearly 80 % of the figure. That is to say, it is also effective to concentrate the pipe replacement measures into Block 1.

It is difficult to provide concrete suggestions about “Water pressure control” due to few data. However I guess that effect of water pressure must be further bigger than expected in the pipe network of Maribor Waterworks that has long low-quality plastic pipes.
Of course, some of staffs in Maribor Waterworks have recognized the importance of water pressure control, and they have been conducting such measures as introducing new pumps that reduce water hammer, controlling out-put pressure depending on consumption, separating higher places as a small distribution blocks, or setting up reducer valves.
However I think it is not enough to study the result of these measures. It is necessary to set up water pressure gauges in the network and to analyze relations between leakage and water pressure. It is provable that “Water pressure control” should be most effective and low-cost measures especially for such a pump-up water supply system as Maribor Waterworks has adopted.

Table 3 Priority of replacement

	First Priority			Second Priority				Total
Municipality	PEHD	PVC	Total	PVC	GS	AC	Total	
Maribor	103.06	34.67	137.73		14.35	28.75	43.10	180.83
Miklavz				3.55			3.55	3.55
Hoce	8.73		8.73					8.73
Pesnica				8.33			8.33	8.33
Ruse	8.43	2.23	10.66					10.66
Selnica								
Lenart	28.08	2.93	31.01		1.37		1.37	32.38
Benedikt		4.06	4.06					4.06
Sv. Ana		0.77	0.77					0.77
Sentilj					0.07		0.07	0.07
Duplek	28.71		28.71	1.59			1.59	30.30
Kungota				9.53			9.53	9.53
Total	177.00	44.66	221.66	23.00	15.79	28.75	67.54	289.20
Block 1	140.49	34.67	175.16	5.14	14.35	28.75	48.24	223.40
Block 2	8.43	2.23	10.66	0.00	0.00	0.00	0.00	10.66
Block 3	28.08	7.76	35.84	17.86	1.44	0.00	19.30	55.14