

Use of the Infrastructure Leakage Index (ILI) in Malaysia

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ABSTRACT

In Malaysia, PABW Sdn. Bhd. (a joint venture company between Premier Ayer Sdn. Bhd. of Malaysia and Bristol Water Services of UK) has been successfully applying the ILI methodology, and its underlying physical concepts of Burst and Background Leakage Estimation (BABE) and Fixed and Variable Area of Discharge (FAVAD) concepts, to determine the level of leakage within discrete network zones prior to carrying out leak detection and repair works.

A full set of data from 93 NRW Zones has been analysed. Each of these zones contains around 800 service connections and varies considerably in nature – high pressure, low pressure, high connection density, low connection density, high level of Real Losses, low level of Real Losses, etc.

The calculated Infrastructure Leakage Index (ILI) values appear to vary considerably from Zone to Zone with values as high as 485 to values as low as 3. The measures taken to reduce the level of Real Losses are detailed in the paper and it is demonstrated that significant savings in leakage can be achieved without recourse to wholesale infrastructure replacement.

KEYWORDS

Non Revenue Water, Infrastructure Leakage Index, Leakage Reduction, Pressure Management, Real Losses, Burst and Background Estimates, Performance Target Based NRW Reduction Contract

INTRODUCTION

Throughout the world, many public utilities suffer from high levels of Non-Revenue Water (NRW). To address this problem and to offer water utilities an alternative approach to effectively reducing NRW, BWS has developed the concept of Performance Based NRW reduction contracts.

This concept was introduced in Malaysia to address the problems of water shortages faced in the State of Selangor, where BWS are now undertaking what is probably the world's largest contract of this type. Selangor is one of the 11 States of Malaysia, home to more than 5 million people (more than 20% of Malaysia's total population). This area also includes the Federal Territory of Kuala Lumpur, Malaysia's Capital which is also included in the Selangor Non-Revenue Water Reduction Project (Liemberger, 2002).

The concept was straight forward: 'No Cure-No Pay'. The overall target of the project was to reduce NRW by more than 200,000 m³/day (73 M m³/year – 25% of the present losses) over a 10 year period.

As a first phase, a pilot project (duration 18 month) was executed. It was completed in March 2000 and all contractual targets were achieved or exceeded.

Although Phase 1 was a small pilot project, the achievement of the performance targets was important as it (i) proved that the concept works and (ii) was a precondition for the second phase of the project.

Table 1 below provides the details:

Component	Target [m ³ /d]	Achieved [m ³ /d]	Ratio of Achievement [%]
Physical Loss Reduction	10,450	11,429	109
Meter Accuracy Improvement	6,400	9,212	144
Illegal Connections		257	
Total NRW Reduction	18,540	20,898	113

Table 1: Selangor Phase 1 Target Achievement

Convinced by the success of the pilot project, the Client awarded a contract for a 9-year project with a loss reduction target of 198,900 m³/day. The project commenced in April 2000. Phase 2 is now in its third year. During the first two years all targets were exceeded. Figure 1 below shows the annualised performance targets and the actual performance achievements during years one and two.

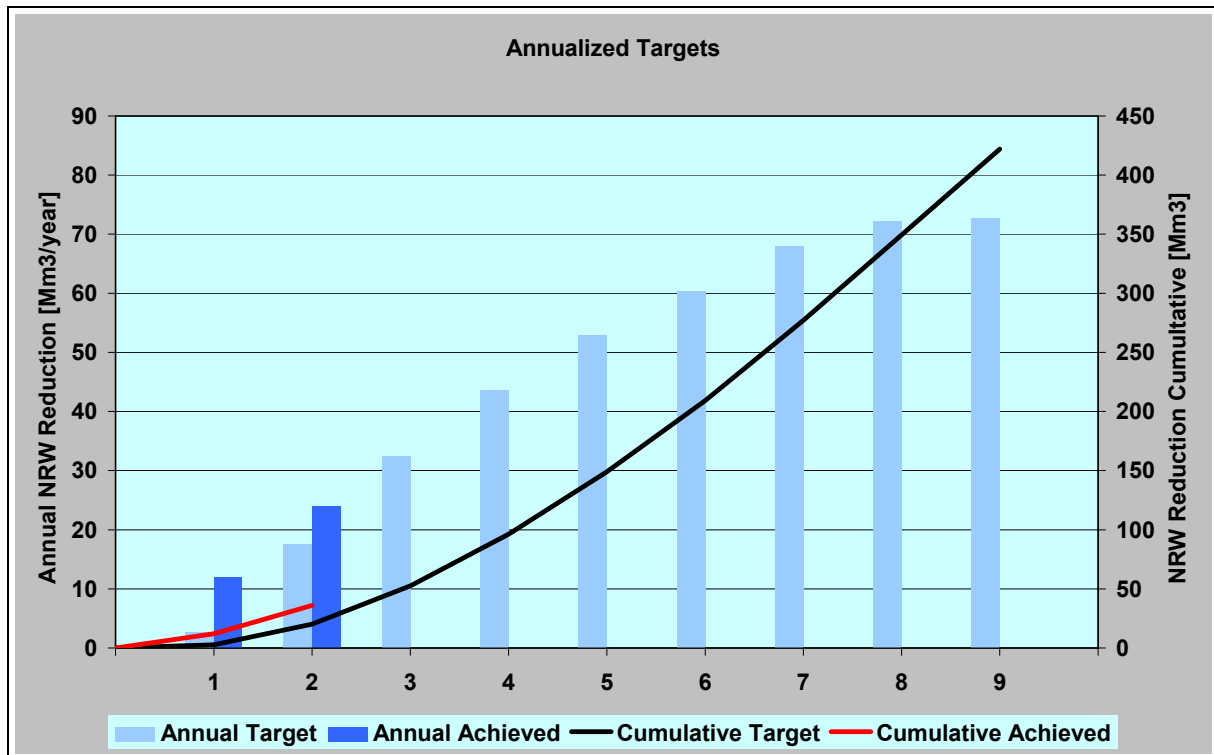


Figure 1: Annualized Performance Targets and Achievements

BWS is successfully applying the ILI methodology, and its underlying physical concepts of Burst and Background Leakage Estimation (BABE) and Fixed and Variable Area Discharge (FAVAD) concepts, to determine the level of leakage within discrete distribution network zones prior to carrying out leak detection and repair works.

The Infrastructure Leakage Index (ILI) gives the ratio between Unavoidable Annual Real Losses (UARL) (which gives the lowest technically achievable level of Real Losses, for well managed infrastructure in good condition) and Current Annual Real Losses representing the level of losses currently occurring throughout the system being analysed. ILI values have been calculated for 93 zones giving the possibility to compare their values before leak detection and after the leak repair works have been carried out.

METHODS AND TECHNIQUES

Water loss reduction in more than 100 NRW zones:

Establishment of NRW reduction zones:

What are the steps to be taken to establish a NRW Zone? Prior to any further steps existing network plans have to be analysed before NRW zones can be selected. Often it is necessary to create new plans due to the lack of systematic network plans. Criteria for the pre-selection of NRW zones are:

- ◆ Potential to be fed through a “Single Fed”, so the inflow to the zone and hence also the achieved reduction of Real Losses can easily be monitored;

- Reasonable pressure not less than 5m, so that leaks can be located with sounding methods;
- Considered to have significant losses (based on first on-site inspections and information from the client), so that the set targets of physical loss reduction can be achieved;
- Size of the zone between approximately 500 and 1500 service connections.

Once zones meeting these criteria have been identified, existing boundary valves are tested and new boundary valves are installed (if necessary) in order to isolate the NRW zone and to create a “Single Feed”. After this, a zero pressure test is carried out to verify that the zone is hydraulically discrete. By closing the Single Feed into the NRW Zone the pressure within the zone has to drop to zero. This confirms that all boundary valves are tight and no unidentified interconnection to another zone exists.

After that a first BABE analysis is carried out using the data recorded with portable flow meters and the pressure loggers installed within the NRW Zone. This permits an estimate to be made of the volume of physical losses in the zone.

Once the zone meets all requirements mentioned above, a Permanent Bulk Meter Chamber is constructed. This installation consists of a bulk meter and a pressure control valve with a bypass. Additionally a strainer is installed to protect the bulk meter. Both flow and pressure are monitored with electronic data loggers to guarantee the precise recording of flow and pressure into the zone. A large part of the zones already established, have telemetered data loggers in use.

After the permanent bulk meter installation is commissioned, first baseline flow and pressure measurements for 7 days are carried out in order to measure the average daily inflow to the NRW Zone and the pressure at, at least three locations throughout the NRW Zone. Pressure monitoring locations are the Inlet Point, the Average Zone Point and the point of lowest pressure. To determine the consumption, all meters of large customers are read at the beginning and the end of the monitoring period. The consumption of small customers is calculated from customer billing data.

The level of Real Losses is defined as: $Q_i - M_i$ where

Q_i = the average daily inflow to the NRW Zone as measured over a period of seven days, prior to starting leakage reduction activity;

M_i = the average daily metered consumption within the NRW Zone over a period of seven days prior to starting leakage reduction activity.

Leak detection and Repair:

After the level of physical losses has been determined and approved by the client, leak detection and repair can be started.

The first activity is a visual inspection of the zone to locate all visible leaks. An initial survey of service connections is carried out in order to determine whether a full scale connection replacement is necessary or not and based on these findings a replacement of service connection and pipes is carried out.

Based on the gained experience it is anticipated that there will be many leaks on service connections, mainly at the tapping point. This is mainly due to the poor standard of workmanship used at the installation and as well the poor quality of materials used (insufficient galvanised cast iron and mild steel nuts and bolts). This in connection with aggressive soil results in a high quantity of corroded service connections.

The replacement of service connections results in a reduction of Real Losses often hard to be located with sounding methods and eliminates many leak noises that then facilitate the location of pipeline bursts in the Zone.

The next step is Leak noise sounding using both traditional equipment such as listening sticks as well as contact microphones, leak noise loggers and leak noise correlators. However, the major part of leaks repaired is located with traditional listening sticks.

During the leak detection exercises all unauthorised connections located by the leak detection teams are report directly to the client.

By carrying out the leak detection surveys all located leaks are registered on network drawings and this information is forwarded to the repair teams. Repairs are carried out by various sub contractors under the supervision of PABW and in co-ordination with the client using only high quality repair materials purchased by PABW. All repair materials used are of high quality such as epoxy-powder-coated Pipe Saddles, which are fitted with stainless steel bolts, Stainless Steel Pipe Repair and Coupling Clamps, etc.

As a matter of fact in systems operating at low pressure with high leakage levels the average pressure in the zone rises after extensive leak repairs have been carried out and this will cause new leaks on the network and a rise in background losses. Therefore pressure management is applied to keep the pressure at the pre - repair level or if applicable to reduce pressure within the Zone to a lower level.

Background leaks occur mainly at joints and fittings, they run continuously but do not generate sufficient noise to be detected by existing equipment. (Lambert et al, 2002). Therefore the reduction of excessive pressure throughout the zone is the most effective way to reduce the level of Background Losses.

Once all repairs and service connection replacement is completed a final flow and pressure measurement over a seven day period is carried out to calculate the average daily inflow to the zone. The consumption is calculated in the same way as applied for the first baseline flow and pressure measurement.

The reduction of Real Losses achieved by leakage reduction are calculated as:

$$(Q_i - M_i) - (Q_e - M_e) \quad \text{where}$$

Q_i = the average daily inflow to the NRW Zone as measured over a period of seven days, prior to starting leakage reduction activity;

Q_e = the average daily inflow to the NRW Zone as measured over a period of seven days, following completion of leakage reduction activity;

M_i = the average daily metered consumption within the NRW Zone over a period of seven days prior to starting leakage reduction activity;

M_e = the average daily metered consumption within the NRW Zone over a period of seven days following completion of leakage reduction activity.

Calculation of ILI:

The ILI is the IWA 'Best Practice' Level 3 Performance Indicator for Operational Management of Real Losses (Alegre et al, 2000). The ILI is the ratio of the Current Annual Real Losses (CARL) to the Unavoidable Annual Real Losses (UARL). It is recommended following the current knowledge and experience that the UARL can be calculated for any system or sub-system with:

- more than - 5,000 service connections;
- density of connections - greater than 20 per km of mains;
- average operating pressure - more than 25 meters.

For smaller systems the Unavoidable Background Losses (UBRL) can be calculated (working to even lower pressure and connection densities) for analysis of night flows (Lambert, 2002). As all of the established zones have less than 5000 service connections and the operating pressure is often less than 25 m the UBRL have been calculated to determine the ILI of each NRW Zone.

The ILI was calculated as follows:

$$ILI = CRL/UBRL$$

The Current Real Losses (CRL) are the Real Losses calculated by deducting the average daily metered consumption within a NRW Zone (Mi) from the average daily inflow to the NRW Zone, both measured over a 7 day period.

The equation used to calculate the UBRL was:

$$UBRL \text{ (litres/service conn.day)} = (9.6/DC + 0.6 + 16 \times Lp/Nc) \times P$$

where DC = density of connections/km mains; Lp = total Length of private pipe, property line to customer meter (km); Nc = Number of service connections; P = average pressure (meters)

Due to the situation found in Selangor, where the customer meter is located at the property line, for Lp a value of 0 is used for the calculations.

The values used to calculate the UBRL, are taken from 'Practical Experience in using the Infrastructure Leakage Index', Table A2 (Lambert, 2002).

Infrastructure component	Background leakage	Units
Mains	9.6	l/km mains/day/m of pressure
Service connection, mains to property line	0.60	l/serv.conn./day/m of pressure
Underground pipe, where customer meter is located after property line	16.0	l/km of pipe/day/m of pressure

RESULTS FROM ANALYSING 93 NRW ZONES:

93 NRW Zones and their general characteristics:

Infrastructure characteristics of zones:

A data set of 93 NRW Zones which have been implemented over the last three years has been subject of the conducted analysis. The general characteristics of the Zones analysed are represented in Table 2 below.

	Nr. of Connections	Length of Main	Connection Density
	nr	km	nr/km
Maximum	3,030	69	296
Minimum	187	2	12
Average	845	12	114

Table 2: Infrastructure Characteristics of Zones analysed

The zones show a wide range of Infrastructure characteristics, due to the fact that the existing network does not always allow establishment of zones of an ideal size. By subdividing the network into monitorable NRW Zones, it must be guaranteed that the current supply situation and system pressure is not negatively influenced by creating hydraulically discrete zones.

Pressure:

The pressure within the NRW Zone is one of the most important components influencing the level of Real Losses. It affects the rate at which losses flow from the system and also has a major effect on the frequency with which new leaks and bursts occur (Lambert, 2001).

From analysing the pressure levels of the 93 NRW Zones it appears that the average pressure before leak repairs and pressure management have been carried out is on average 26m. The levels of pressure throughout the Zones vary from as low as 7m up to 63m . The pressure data (Table 3) shows that pressure in zones with high pressure levels were reduced substantially and as well that the pressure levels on average have been reduced by applying pressure management. This is the most effective way to reduce Background leakage and to avoid new leaks occurring due to rising zone pressure caused by extensive leak repair.

An important remark is that those reductions in zone pressure have been achieved without affecting the consumption in a negative manner, on the contrary most zones show higher consumption after the leak repair campaign and introduction of pressure management.

This is explained by the fact that by eliminating a major part of bursts and leaks the pressure is sufficient to guarantee better supply during peak demand hours. A graph of zone pressure levels before leak repair and after is shown in Appendix, see figure A 1.

	Pressure before leak repair	Pressure after leak repair
	[m]	[m]
Maximum	63	40
Minimum	7	6
Average	26	17

Table 3: Pressure within 93 NRW Zones

Level of Real Losses [l/conn/day/m pressure]:

The level of Real Losses within NRW Zones is calculated using the methods explained before. As system pressure within the 93 NRW Zones varies widely the level of losses is best compared when calculated in litres/service connection/day/meter pressure. Generally it can be said that the level of Real Losses found in the selected zones is high due to bad condition of infrastructure although the pressure levels are low compared to western systems.

Table 4 shows that on average for the 93 NRW Zones the level of Real Losses has been reduced substantially from 69 l/conn/day/m down to 39 l/conn/day/m and it shows as well that some zones suffered enormous Real Losses and in some cases those high losses have been reduced only to a certain extent. By grouping the level of Real Losses into four main categories a clearer picture of achieved loss reduction appears. The quantity of zones with Real Losses between 0 and 10 l/conn/day/m has risen from 5% to 17% after leak repair and pressure management have been completed. These are levels of Real Losses comparably with losses achieved in well managed systems (e.g. Bristol Water plc. Level of Real Losses 2001 was 2.6 l/conn/day/m). The quantity of zones where the level of losses is higher than 30 l/conn/day/m have diminished from as much as 65% to 35 percent.

	Rreal Losses before leak repair	Real Losses after leak repair
	[l/conn/day/m]	[l/conn/day/m]
Maximum	397	224
Minimum	4	3
Average	69	39

Category of Real Losses	before leak repair	after leak reair
[l/conn/day/m]	%	%
0 to 10	5%	17%
11 to 30	30%	48%
31 to 100	47%	24%
> 100	18%	11%

Table 4: Level of Real Losses before and after leak repair has been carried out

Reduction of Real Losses:

As mentioned in the paragraph above the level of Real Losses does vary substantially within the 93 NRW Zones and so does the achieved reduction of Real Losses. In accordance with the client mainly zones with very poor infrastructure condition and hence high level of Real Losses are selected.

In this way the cost benefit ratio is the highest and also the time needed to achieve considerable reductions of Real Losses is much less and hence more NRW zones can be created. And as a certain number of NRW zones has to be established during the project phase the time needed for each zone until it is completed is a significant factor for PABW. To reduce the level of Real Losses down to levels achieved in well run systems, would not be economic for PABW, as within the contract no incentives are seen if the targets are overachieved.

Reduction of Real Losses	Min	Max	weighted Average
l/conn/day	38	5,553	603

Table 5: Reduction of Real Losses

The achieved reduction of Real Losses in 93 NRW Zones was on average 603 l/conn/day. But the range of loss reduction varies widely from as few as 38 l/conn/day to as much as 5,553 l/conn day. The NRW Zone where the achieved reduction of Real Losses was only 38 l/conn/day is a Zone that for local circumstances had already a very low level of Real Losses (338 l/conn/day or 13 l/conn/day/m) when the leak detection and repair campaign started.

Detailed analysis of Real Loss Reduction and the Performance Indicator ILI:

Analysing the reduction of Real Losses within 93 NRW Zones shows clearly that with rather simple methods (creation of hydraulically discrete zone, standard leak sounding and pressure management) a reduction of 57% of Real Losses has been achieved (Table 6).

Weighted Average of Real Losses	before leakage reduction	after leakage reduction
l/conn/day	1,053	450

Table 6: Weighted Average Real Losses

Not only the weighted average of Real Losses indicated the high level of loss reduction but also by grouping the Real Losses of each individual zone into categories gives a clear picture of achieved loss reductions (Figure 2).

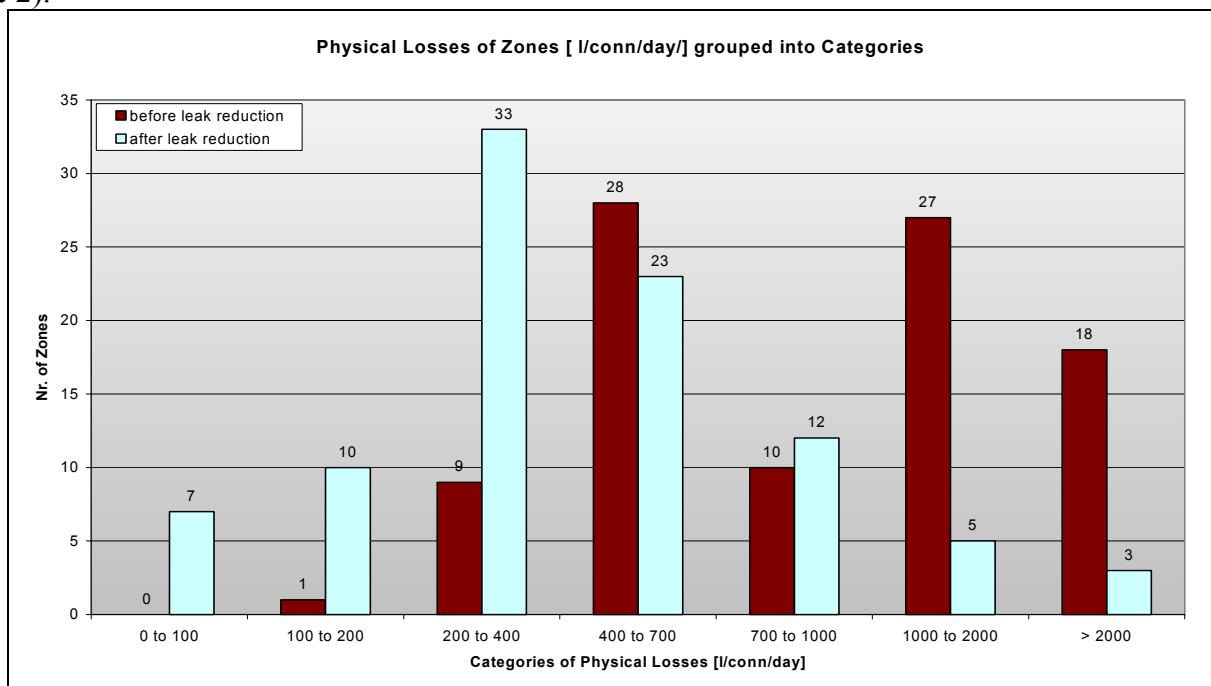


Figure 2: Categories of Real Losses before and after leakage reduction

Before leakage reduction has been carried out the vast majority (89%) of NRW Zones had losses greater than 400 l/conn/day, after leakage reduction has been completed 54% of NRW zones had losses less than 400 l/conn/day. The huge number of zones showing losses higher than 1000 l/conn/day before leakage reduction has also been substantially reduced.

In general it has to be said that the ILI values found are very high compared to values found in western European systems. The ILI values have been substantially reduced but appear to be still high after leak repair has been carried out.

ILI	Min	Max	Average
before leakage reduction	6	485	88
after leakage reduction	3	246	62

Table 7: general characteristics of calculated ILI values

The average ILI value for all analysed NRW zones before leak repair has been carried out is 88. This value was reduced by 30% down to an average ILI of 62 after the leak repair has been completed

In general, the ILI values found have a huge variation from values as low as in well managed European systems to values as high as 485. Those high values have been caused by bursts that have not been considered and repaired for many years by the responsible water utility. Figure A2 in the Appendix shows the calculated ILI values for all NRW Zones before and after leak repair has been carried out.

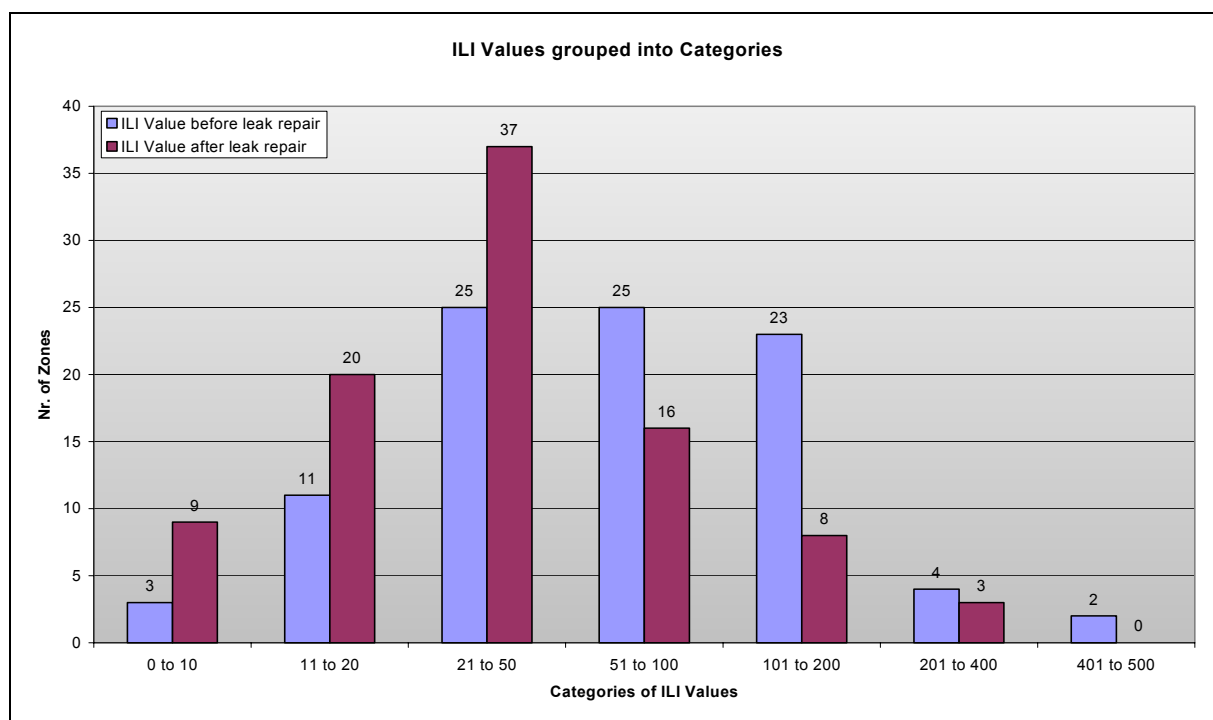


Figure 3: Categories of ILI Values before and after leakage reduction

Figure 3 shows that with the leakage reduction measures carried out, the quantity of zones showing values below an ILI of 50 has increased from 42% to 72%.

Table 8 shows a data set of international ILI values compared with the average ILI values found in 93 NRW Zones in Malaysia before and after leak repair was carried out.

Data Set / Region	Connection Density (no./km)	Average System Pressure (m)	CARL (l/conn/d)	ILI
93 NRW Zones in Malaysia before leak repair	114	26	1,053	88
93 NRW Zones in Malaysia after leak repair	114	17	450	62
Soroca - Moldova	47	22	1,050	81
Criuleni - Moldova	26	21	377	12
Karaganda - Kazakhstan	26	23	1,739	51
Bukhara - Uzbekistan	39.0	20.0	2,316	92
Dushanbe - Tajikistan	56.0	16.0	4,989	278
Europe	55.5	35.0	29	0.70
Europe	46.6	57.3	146	1.31
Europe	71.7	46.0	104	1.62
Europe	39.4	35.0	107	2.00
Europe	31.2	70.0	342	3.25
Europe	65.0	30.0	180	4.99
Europe	37.1	46.0	320	5.42
Europe	28.6	35.0	477	7.06
Asia-South East & Pacific	79.0	31.0	256	8.02
Europe	23.8	45.0	832	10.25
America – North	92.6	39.0	527	10.86

Table 8: Comparison of international ILI values with values found in 93 NRW Zones in Malaysia

Comparing the results with an international data set, it appears that the average ILI value achieved in 93 NRW Zones after leak repair has been carried out, are partly comparable with values found in Central Asia and Eastern Europe and considerably higher than in European systems. But and this was the main goal of the project, the level of Real Losses was reduced down to less than 50% of its initial value.

A graph showing the ILI values of 93 NRW Zones before leak repair and the accompanying achieved reduction of Real Losses is shown in the Appendix, see figure A3. This graph is representative for all comparisons carried out trying to cross correlate infrastructure parameters, physical parameters and Performance Indicators. It appears that the achieved loss reduction as well as the performance indicators of each NRW Zone are influenced by numerous factors but they are showing no compelling “cause and affect” links.

CONCLUSIONS:

Generally it can be said that the infrastructure throughout Selangor is in considerably bad condition and by applying network zoning and monitoring, leak detection, pressure management and by the use of high quality repair materials all set targets of physical loss reduction have been achieved without recourse to wholesale infrastructure replacement.

Analysing the data, it appears that the ILI values are still high after leak repair in NRW Zones has been completed. But the quantity of NRW Zones showing ILI values above 50 has been substantially reduced. But more important and meeting the goal of the project a reduction of Real Losses of about 47,000 m³/day has been achieved within these 93 NRW Zones.

Finally it has to be said that the results of the analysis reflect the prevailing conditions. The Real Losses have been reduced substantially and in a cost effective way with performance indicators showing that the condition of the infrastructure is still not comparable with western systems, but compared to local supply systems a considerable improvement of ILI values was achieved.

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APPENDIX

Figure A1: Comparison of Average NRW Zone pressure before and after leak repair has been carried out.

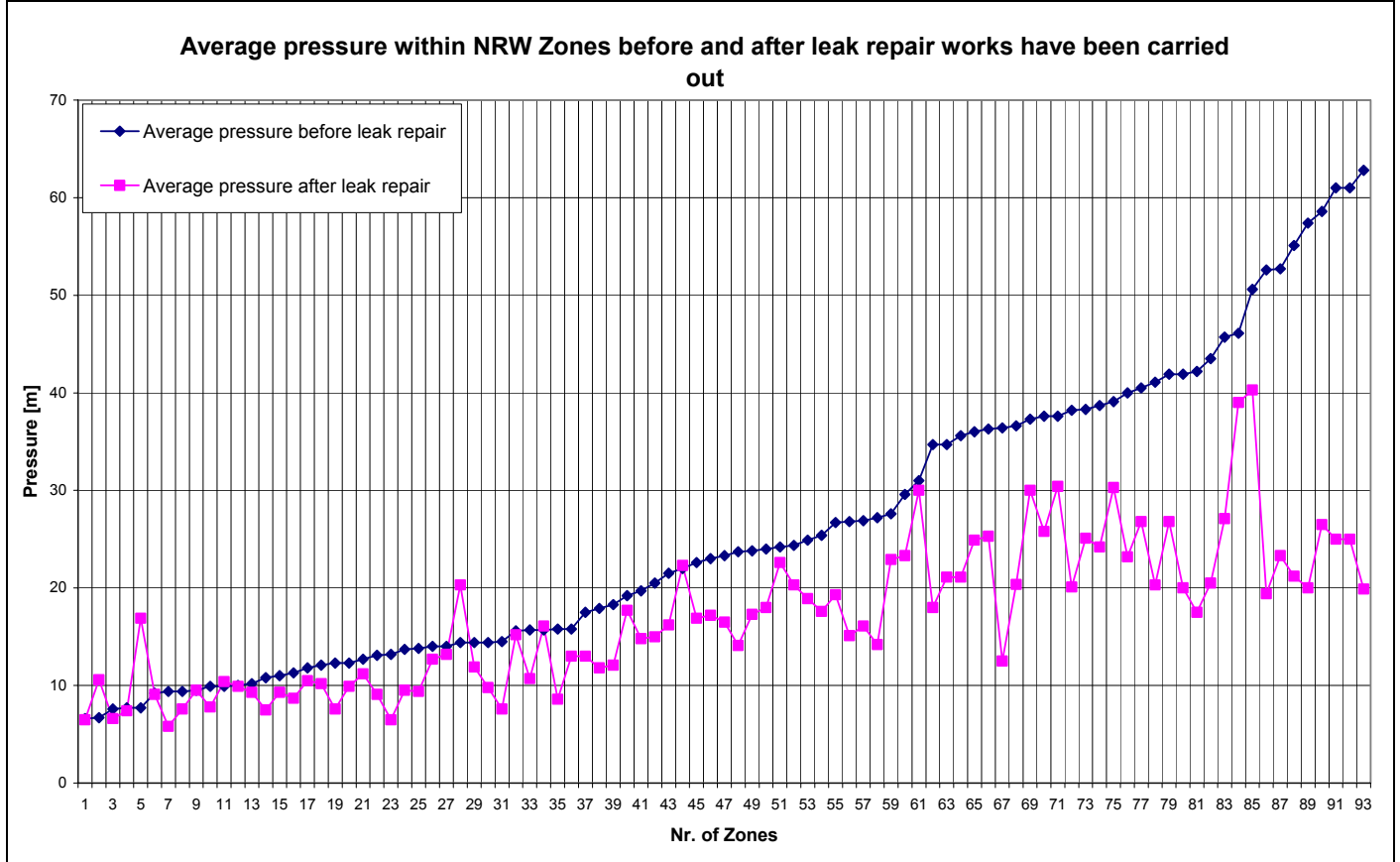


Figure A2: Comparison of ILI values within the NRW Zones before and after leak repair has been carried out.

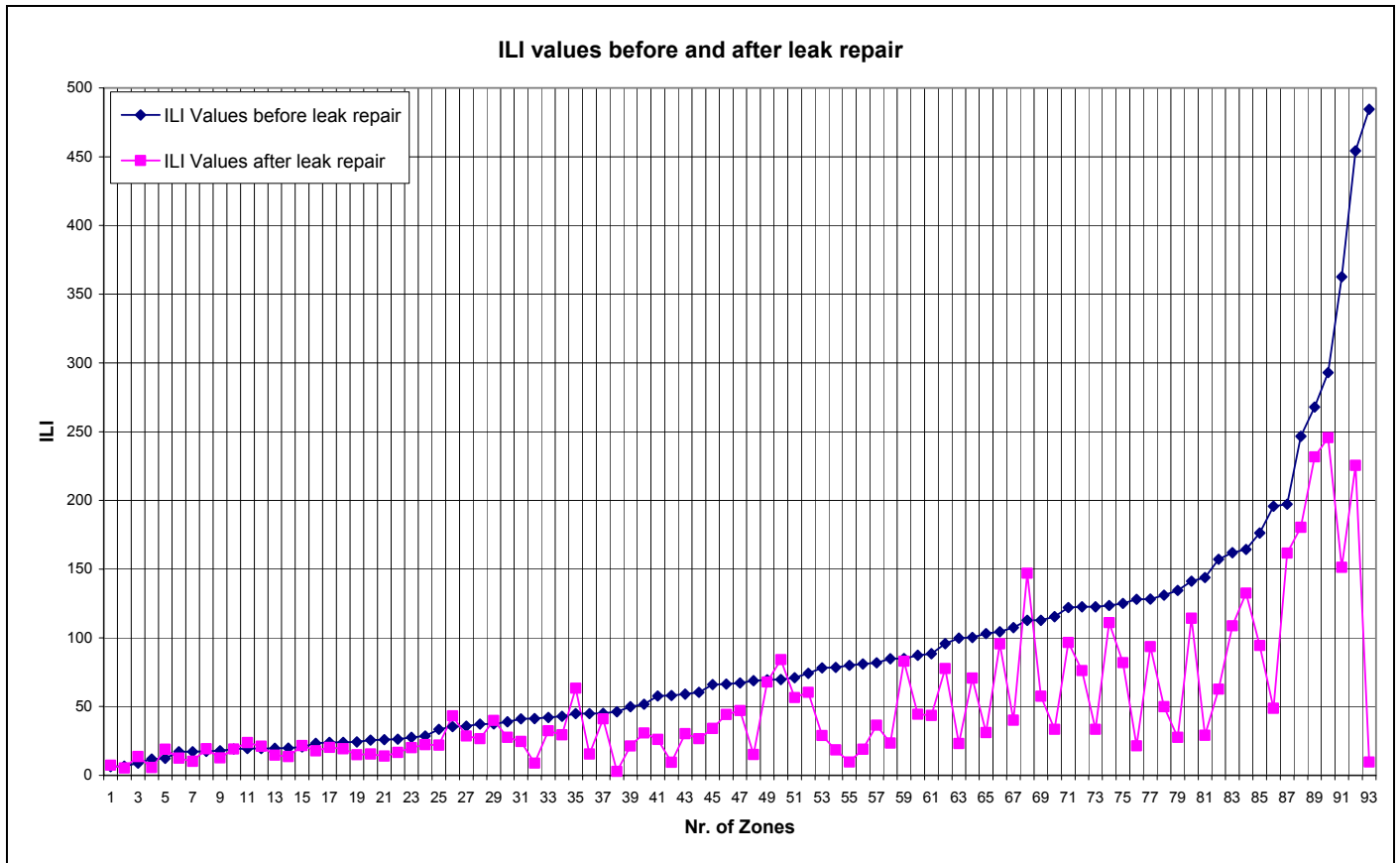


Figure A3: Comparison of ILI values before leak repair and accompanying Final Savings

