Experiences in DMA redesign at the Water Board of Lemesos, Cyprus

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Abstract

It is evident that water is a limited resource in arid and semi-arid regions of the world, a situation that has highlighted, among other things, the need to reduce leakage from urban water distribution systems to levels that are considered economically acceptable.

This paper reviews the experiences gained at the Water Board of Lemesos in striving to achieve lower levels of leakage by DMA resizing and subsequently applying a pressure reduction programme. An account of the work carried out in redesigning DMAs is given as well as the results obtained in further reducing leakage from the distribution system by pressure reduction and control to economically acceptable levels and to maintaining these levels through the adoption of an effective active leakage management strategy.

Introduction

Water shortage and the future threat posed by changing climatic conditions has intensified the need for the development of appropriate water management approaches, which aim in keeping a balance between water supply and demand.

Losses from water distribution systems must be of concern to every water utility, especially in areas of our planet where water is found in very limited quantities. It is therefore imperative that water utilities apply simple and effective methodologies in accounting for water losses from their transmission and distribution systems. The International Water Association (IWA) has established a water audit method, which traces water from its source right through the system and derives at the end the revenue and non-rename component.

The Water Board of Lemesos recognised at a very early stage the importance and significance of establishing a proper water audit system and has over the years developed its infrastructure in such a way in order to be able to account efficiently and accurately for all water produced.

Water Balance

A water audit for the year 2003 using the IWA ‘best practice’ water balance and terminology (Task Force on Water Losses, 2000) is shown in Table 1 for the whole of the Water Board’s supply system.

Table1. Water balance (m^3) for the year 2003

<table>
<tr><td rowspan="11">System
Input
Volume
11.985.560
100,00%</td><td rowspan="4">Authorised
Consumption
10.276.626
85,74%</td><td rowspan="2">Billed
Authorised
Consumption
10.216.698
85,24%</td><td>Billed metered consumption
(including water exported)
10.216.698
85,24%</td><td rowspan="2">Revenue water
10.216.698
85,24%</td></tr>
<tr><td>Billed unmetered consumption
Zero</td></tr>
<tr><td rowspan="2">Unbilled
Authorised
Consumption
59.928
0,50%</td><td>Unbilled metered consumption
Zero</td><td rowspan="9">Non-revenue water
1.768.862
14,76%</td></tr>
<tr><td>Unbilled unmetered consumption
59.928
0,50%</td></tr>
<tr><td rowspan="7">Water Losses
1.708.934
14,26%</td><td rowspan="2">Apparent
Losses
299.639
2,50%</td><td>Unauthorised use
59.928
0,50%</td></tr>
<tr><td>Metering inaccuracies
239.711
2,00%</td></tr>
<tr><td rowspan="5">Real Losses
1.409.295
11,76%</td><td>Real losses on raw water mains and at the treatment works
Zero</td></tr>
<tr><td>Leakage on transmission and/or distribution mains
80.458
0,67%</td></tr>
<tr><td>Leakage and overflows at transmission and/or distribution storage tanks
11.986
0,10%</td></tr>
<tr><td>Leakage on service connections up to the metering point
268.913
2,24%</td></tr>
<tr><td>Detectable Losses
1.047.938
8,74%</td></tr>
</table>

Authorised Consumption

As it can be seen from the above table almost all consumption is registered under the Billed Metered Consumption components since all supplies within the Water Board's area are metered. In exceptional cases the Fire Brigade may take water from fire hydrants in the distribution network without the knowledge of the Water Board. This quantity is very small and an estimate of 0,5% of the System Input Volume is entered under the Unbilled Unmetered Consumption Component.

Water Losses

The Water Losses from the system are made up of Apparent Losses and Real Losses. These losses together with the Unbilled Authorised Consumption comprise the Non-Revenue Water (NRW). Apparent Losses are valued at retail billing rates whereas the Real Losses are valued at the variable cost of water production and distribution (Thiemann, R. and Henessy, S. 2005). Therefore the Water Board considers that the reduction of Apparent Losses is as important as the reduction of Real Losses.

Apparent Water Losses

The Apparent Losses sometimes referred to as "paper" losses, consist of two main components, (i) metering inaccuracies and (ii) Unauthorised Consumption.

The Water Board has developed policies for water meter management, which include the following:

- periodical checking and replacement if necessary of all source, storage and DMA meters,
- use of high accuracy domestic meters.

The domestic meters are checked every four months, when they are read by the meter readers, and malfunctioning or damaged meters are reported and replaced with new ones. In addition a replacement programme for ageing domestic meters is effected every year with the aim to replace meters which are over 10 years old. This means that every year about 6000 meters are replaced.

Furthermore meter reading and billing errors have been minimised with the use of portable meter reader recorders. We therefore believe that this component of the water balance has been reduced and is maintained at low levels and a figure of 2% of billed metered consumption is reasonable to assume.

The other component of Apparent Water Losses is that of unauthorised or illegal consumption which could be made up of all or a combination of the following:

- consumers using water without being metered or paid for,
- illegal reconnection of a service which has been disconnected by the Water Board,
- by-passing of the water meter with an illegal connection,
- unauthorised consumption from fire hydrants.

To assist in detecting unauthorised consumption the Water Board has applied the following strategy:

- reviewing at every billing cycle, which is every four months, all active accounts with no or very small consumption as well as all inactive accounts,
- investigating inactive accounts with consumption,
- examining unusual observations by meter readers or others, and
- inspecting all unmetered fire hydrants.

The above strategy has been very effective and the Board has succeeded in maintaining this component of the Water Balance at low levels. A reasonable estimate of this component would be about 0,5% of the System Input Volume.

Real Water Losses

The IWA recommended definition of Real Water Losses, sometimes referred to as "physical losses", is the annual volumes of water lost from the system through all types of leaks and overflows from reservoirs and from bursts in mains and service connections up to the point of customer metering (Fanner, P. 2004). The Water Board has placed great importance in reducing the real losses and this is reflected in its adopted strategy over the years.

The development of the system infrastructure took place in a very organised fashion with new areas of supply being incorporated into their respective pressure zones, which are strictly governed by contours. Each pressure zone is subdivided into DMAs, having a single metered source with physical discontinuity of pipe network between DMA boundaries.

The DMAs vary in size from 50 properties to 6.800 although the average size being approximately 3000 properties. Distribution main diameters within the DMAs vary between 100mm and 250mm and where possible, interconnecting ring systems within the DMAs have been formed to minimize head loss at peak demands.

The Water Board has maintained records of its operational activities since 1963, which include production of water from sources, distribution through district meters and consumption from consumer meters. Meter readings at water sources (boreholes and treatment plant) are connected via a SCADA telemetry system to the control room. This enables continuous monitoring of the water source outputs and accurate recording of flows. Likewise storage reservoir outlet meters are monitored on SCADA providing the same ability to observe trends as well as to record daily, weekly, monthly and yearly totals.

As all the trunk mains, made of ductile iron, are purely dedicated to transferring water from sources to the storage reservoirs, it is possible to carry out a balance between production meters and storage reservoirs outlet meters. The results show that on a yearly basis the difference between the production meters and reservoir outlet meters is less than 1% which is considered to be negligible and is attributed meter registration errors. Distribution of water to the DMAs is effected through dedicated ductile iron mains from the storage reservoirs. Each pressure zone has its own dedicated storage reservoir supplying the DMAs within the specific pressure zone. Each DMA has a single feeding point, which is metered. With this arrangement it is possible to carry out a water balance between the storage reservoir outlet meters and the DMA meters. The results show that on a yearly basis the difference is about 2%, which is attributed to meter inaccuracies.

Therefore it could safely be assumed that all real water losses are within the DMAs.

DMA redesign

The Water Board operates seven pressure zones each fed by gravity from a dedicated storage reservoir. Table 2 shows the percentage water input into each pressure zone and the number of DMAs in each pressure zone.

From the table it can be seen that 86% of the flow is in pressure zones 1 and 2. Therefore it was considered important to first carefully examine the size of the DMAs in pressure zones 1 and 2 in an effort to further reduce the real losses from the system and being able to provide better and more effective active leakage control.

Table 2. Water supply to pressure zones

Pressure Zone	Water input (% total)	No. of existing DMAs
1	47	9
2	39	9
3	9	3
4	3	2
5	1	2
6	0,6	1
7	0,4	1

The key factors for good DMA design (Water Loss Task Force, 2004) formed the basis of the redesign. These were:

- minimum variation in ground level across the DMA,
- easily identified boundaries that are robust,
- area meters correctly sized and located,
- single entry point into the DMA,

- discrete DMA boundaries,
- pressure optimised to maintain standard of service to customers,
- degree of difficultly in working in urban area.

The variation in ground levels across the study area was examined and particular attention was given to the influence of the pressure within the DMA. Main highways and physical feature such as streams were chosen to form discrete boundaries between DMAs. A single entry point into the district was chosen where a meter chamber was constructed to house the district meter, a pressure reducing valve and a pressure sensor. It must be stressed that the implementation of the redesign was not an easy task due to the difficulties and restrictions imposed in executing works in built up areas. These works involved inter alia, the construction of new district meter chambers, laying new lengths of pipeline and installation of new telemetry system for on-line monitoring of flow and pressure. The result of the DMA redesign in pressure zones 1 and 2 is shown in Table 3 below.

Table 3. District Metered Area redesign

Description	Total number of DMAs	DMA category		
		Small <1000 properties	Medium 1000 – 3000 properties	Large 3000 – 5000 properties
Zone 1 before After	9 17	1 6	5 11	3 0
Zone 2 before After	9 15	2 9	4 5	3 1

It is evident from Table 3 that the redesign process yielded DMAs of smaller, more manageable size with physical pipework discontinuity between DMAs. In order to verify that all interconnecting pipes between DMAs were located and isolated a zero pressure test was carried out which involved closing the valve at the inlet to the DMA thus isolating the DMA and observing that the pressure within the DMA dropped immediately indicating that all interconnecting pipes were isolated. This test was usually carried out between 02:00 and 04:00 in the morning in order not to inconvenience consumers.

DMA inlet chamber

Each DMA is provided with an inlet chamber which houses a strainer for meter protection, the district water meter, a pressure reducing valve and a pressure sensor.

The selection of the flow meters was based on the historical data available of minimum, average and peak flows taking into consideration seasonal variations. The meters chosen were low cost mechanical “Waltman” type of metrological class B with pulse output having a flow range up to 200 m^3/hr. Most DMAs required a 100mm nominal diameter meter with the larger size DMAs needing a 150mm nominal diameter.

The pressure reducing valves (PRVs) were chosen to have remote close/open capability with 12V DC latching solenoids. The size of the PRVs was standardised to 150mm nominal diameter which covered the flow requirements of all the districts, thus minimising the range of spare parts needed resulting in easier maintenance. It should be noted that PRVs were installed even in areas that minimal or no pressure reduction could be effected in order to stabilize and control pressure within the DMA.

The pressure sensors installed are of high accuracy, 0-10 bar pressure range, 12V DC, 4-20mA, 2 wire transducers with stainless steel body and IP 68 protection. These are located immediately downstream of the PRVs for continuous pressure monitoring.

*On-line monitor*ing

It is essential, for the effective operation of DMAs, to establish a reliable on-line monitoring system in order to apply best practice DMA management which involves the analysis of DMA night flow referred to as the Minimum Night Flow (MNF) in order to assess leakage. For this purpose each district meter is equipped with a programmable controller which is powered in most cases by solar energy panels providing a cheap and effective solution. The programmable controller is performing the following tasks:

- Data logging of flow and pressure
- Control (open-close) of PRV
- Communication with the control room at Water Board's offices via a PSTN line, GSM, ratio or leared line.

The on-line monitoring of the district meters combines information technology and telecommunication networks to transfer the data via the World Wide Web. The historical data gathered in the programmable controller of each DMA are sent by the controller to an email account. Dedicated software operating from a computer at the Water Board's control room connects to this email account every hour and downloads the data, which are first sorted according to the DMA and then are used to update existing reports. Direct access to the programmable controllers from the control room enables modification to the programming of the controllers, downloading of historical data on request and closing or opening of the PRVs. A typical template of the district meter on-line monitoring is shown in Figure 1.

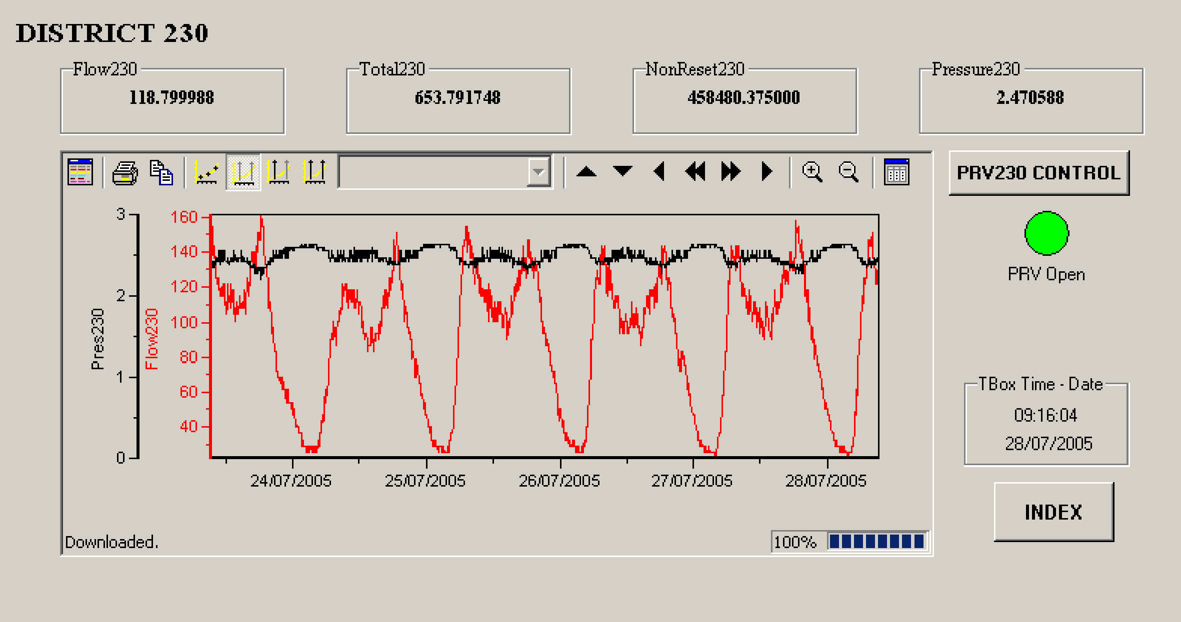

Figure 1. Typical template of the on-line district meters monitoring system

Implementation of the DMA redesign works

The implementation of the DMA redesign works commenced in 2004 giving priority to the areas in pressure zone 2 in order to take advantage of a highway construction which formed a discrete boundary between DMAs. The construction of the highway provided the Board with an excellent opportunity to lay additional pipelines required. All the works needed for the implementation of the pressure zone 2 redesign were completed early in

2005. The implementation of the DMA redesign works for pressure zone 1 is currently underway and is programmed to be completed by the end of 2006.

The redesign works involved the construction of a meter chamber for each district, the laying of a dedicated supply main from the storage reservoir trunk main to the DMA meter chamber and the isolation of all interconnecting pipework to create physical discontinuities between DMAs. It must be noted that the implementation of the DMA redesign works was not an easy task having to work in built up areas where execution of construction works is difficult due to limited space available and restrictions imposed by other services and by the local authorities. The redesign of the DMAs has resulted in producing small to medium size areas of less than 3000 properties each, which can be better managed and controlled, ultimately leading to the reduction of real water losses from the system.

DMA Management

Continuous flow monitoring began immediately upon completion of the redesign works in each DMA. This enabled the establishment of the flow pattern for the DMA providing essential information such as maximum and average daily flows as well as minimum night flows. A typical flow and pressure pattern in a DMA is shown in Figure 2.

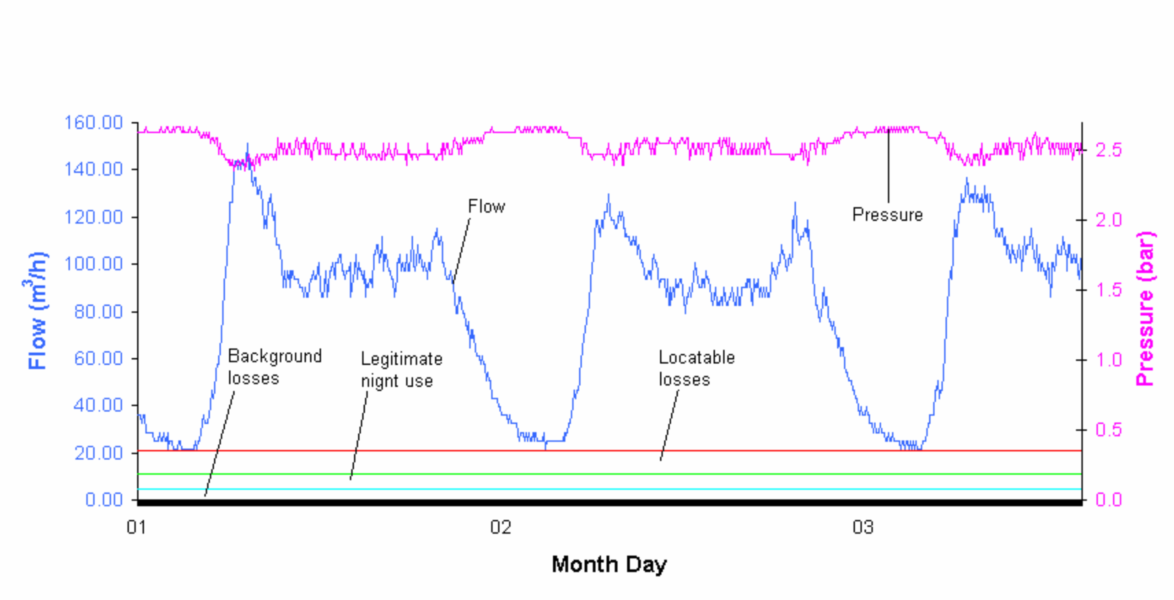

Figure 2. Typical flow and pressure pattern in a DMA

Measurements of pressures within the DMAs were carried out to establish operating pressures at the low, medium and high points of the DMA as well as the Average Zone Night Pressure (AZNP) for each DMA. Furthermore, the pressure measurements were critically examined with the aim to reduce pressure as much as possible whilst maintaining the minimum standard of service to the consumers. As a rule a minimum standard of service of 2 bar at the highest point in the DMA at maximum demand was considered. This of course had to be reconsidered in some cases where there were high rise buildings which used the system's pressure to get the water to their roof tanks. In these cases the Water Board will subsidise the installation of ground tanks and pumping systems in order to pump the water to the roof tanks of the high rise buildings thus enabling further pressure reduction to be effected.

Data required to establish legitimate customer night use and background leakage in each DMA were collected. Having available this information the Burst and Background

Estimates (BABE) component approach to leakage was used to analyse the Minimum Night Flow (MNF).

Pressure Reduction

Management of pressure is a key factor in an effective leakage management policy. This has long been recognised by the Water Board and the ultimate goal is for all DMAs to be equipped with PRVs to reduce pressure where possible and to control and stabilise pressure in DMAs where pressure reduction is not practicable.

Pressure reduction was applied to all the redesigned DMAs in pressure zone 2 taking into consideration the minimum standard of service as outlined in the DMA management section above and the Minimum Night Flow recorded. The reduction of pressure was effected over a period of a few hours and amazingly enough no complaints were received from consumers except in some cases where people were using the mains pressure to water their lawns. It was explained to them that they can not rely on the mains pressure to water their lawns and they were assisted by the Water Board to install small irrigation pumping systems for garden irrigation.

Presentation of results

Background and locatable losses

Having implemented the DMA redesign works data was collected and BABE calculations were carried out in order to determine background and locatable losses for each DMA. A similar calculation was carried out after applying pressure reduction in each DMA. The results of the calculations before and after are shown in Table 4. It must be stressed that the figures for actual MNF are field values measured over a period of approximate one month before and one month after the application of the pressure reduction so that the values of the flows before and after are comparable and are not influenced by seasonal variations.

Table 4. Components of real losses before and after pressure reduction for Pressure Zone 2

DMA	AZNP (m)		Actual MNF (m³/hr)		Background losses (m³/hr)		Legitimate night use (m³/hr)	Locatable losses (m³/hr)	
	before	after	before	after	before	after	before/after	before	after
220	64	32	3,92	2,16	0,63	0,24	1,41	1,88	0,51
221	63	36	5,69	3,85	3,39	1,65	2,13	0,16	0,07
222	54	28	3,07	2,24	1,53	0,71	1,49	0,05	0,03
223	53	29	3,58	2,56	1,70	0,82	1,54	0,35	0,20
224	53	29	5,50	2,52	1,68	0,82	1,59	2,23	0,11
225	64	34	12,96	9,78	5,42	2,41	3,38	4,16	3,99
226	64	34	10,04	6,84	5,62	2,55	4,05	0,37	0,24
227	59	38	15,52	10,44	5,91	3,38	4,50	5,11	2,56
228	43	39	7,60	7,20	3,42	3,03	3,67	0,51	0,50
229	41	36	4,06	3,73	1,13	0,96	0,92	2,01	1,85
230	47	40	21,80	18,00	5,57	4,60	6,86	9,37	6,54
231	52	42	11,01	7,92	4,63	3,54	4,21	2,17	0,18
232	39	32	5,17	4,32	1,32	1,05	1,64	2,21	1,63
233	42	33	4,45	3,96	1,48	1,10	1,49	1,48	1,37
234	48	38	3,55	2,44	0,32	0,23	0,97	2,26	1,24
Total before			**117,92**		**43,75**		**39,85**	**34,32**	
Total after				**87.96**		**27.09**	**39.85**		**21,02**

Looking at the locatable losses before pressure reduction it can be seen that only three from the fifteen DMAs namely: 225, 227 and 230 have locatable losses which are of significance. However, pressure reduction was effected in all DMAs without attempting to locate and fix the locatable losses in these DMAs. The application of the pressure reduction as it can be seen from Table 4 resulted in a reduction of 38,1% in the background losses and in a reduction of 38,8% in locatable losses. It is evident that for twelve of the fifteen DMAs the Economic Level of Leakage has been reached. Priority for locating and repairing leaks has been given first to DMA 230 followed by DMA 225 and 227.

The ratios P_1/P_0 and L_1/L_0 were calculated and the "N1" exponent derived for each DMA as shown in Table 5. The leakage ratio includes both background and locatable losses.

Table 5. Calculation of "N1"

DMA	L_1/L_0	P_1/P_0	N1
220	0,30	0,50	1,74
221	0,48	0,57	1,30
222	0,47	0,52	1,14
223	0,50	0,55	1,15
224	0,24	0,55	2,38
225	0,67	0,53	0,64
226	0,47	0,53	1,21
227	0,54	0,64	1,41
228	0,90	0,91	1,10
229	0,89	0,88	0,85
230	0,75	0,85	1,82
231	0,55	0,81	2,83
232	0,76	0,82	1,39
233	0,83	0,79	0,75
234	0,57	0,79	2,41
		AVERAGE	**1,47**

From the above table it can be seen that the values of N_1 vary between 0,64 and 2,83 with an average value of 1,47. These figures are of the same order of magnitude as figures reported by others (Lambert, A.O. 2001), which reinforce the use of the leakage – pressure relationship $(L_1/L_0) = (P_1/P_0)^{N1}$. The distribution main in all of the DMA's under consideration is a mixture of asbestos cement and uPVC with MDPE communication pipes.

Reported leaks

Records were kept of reported leaks before and after pressure reduction and an analysis of these shows a reduction of leaks both for distribution mains and communication pipes. The results shown in Table 6 cover a period of seven months before pressure reduction and the corresponding seven months after pressure reduction.

Table 6. Reported leaks

Description	No. of leaks reported		Reduction of leaks
	before	after	
Distribution mains	49	27	45%
Communication pipes	296	178	40%

The weighted overall Average Zone Night Pressure for zone 2 was 52,5m before the reduction and 35,8m after. This meant that there was an overall pressure reduction of 32%. Therefore for a 32% overall pressure reduction there was an overall reduction in new leaks on mains, fittings and communication pipes of 41% which compares favourably with a similar case in Australia reported by Lambert, A.O. 2001, where a 40% reduction in one sector of a city reduced frequencies of all new leaks on mains, services and fittings in that sector by 55%. Of course there many other factors affecting burst frequency of mains such as: weather conditions, accidental damages, etc. (Farley, M. and Trow S. 2003).

CONCLUSIONS

The Water Board of Lemesos operates a well-organised supply and distribution system with permanent pressure zones and District Metered Areas thus providing a solid foundation on which an effective leakage control policy has been developed.

The DMA redesign and the application of pressure reduction has produced favourable results with both background leakage and locatable losses being reduced by approximately 38%. Furthermore the frequency of reported leaks was reduced by approximately 41%. The overall pressure reduction for the fifteen DMAs under consideration was of the order of 32%.

The target of the Water Board of Lemesos is to reduce the NRW to about 8% of the system input volume, which is considered to be the economic level of leakage. The Water Board demand forecasts indicate an increase of approximately 30% by the year 2020 and the leakage reduction will go some way towards offsetting this increase in demand as well as a provide considerable cost saving.

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