The Effect of Intermittent Supply on Water Distribution Networks

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The purpose of this paper is to demonstrate the adverse effects of intermittent supply on water distribution networks.

1. The Water Board of Lemesos, established in 1951, is a semi-government Utility (Legal Person governed by Public Law) run by a Board of Directors appointed by the Council of Ministers and local Municipality appointees. The Board aims exclusively to ensure the supply of sufficient quantity water of good quality and to meet both the households' needs and its consumers' commercial and industrial requirements. The main concern and cornerstone of operations is the best possible service offered to its consumers.

Lemesos, on the south coast of the island, is the second largest town of Cyprus. Ground levels in the 100 km^2 supply area fall from 450 meters at the foothills, to sea level. Ductile iron trunk mains supply water to nine major pressure zones, each with a dedicated storage reservoir, which in turn supply 60 DMAs, some of which are also individually pressure-controlled. This strategic design has enabled average pressure to be reduced to 40 metres. All customers are metered and all properties have roof tanks.
Table 1 shows the main characteristics of the water supply and distribution system of the Water Board of Lemesos.

Characteristic	Value
Population	158,000
Number of billed properties (residential and non-residential)	87,640
Number of service connections (main to first meter)	53,040
Average length of underground service connections	8 m
Length of trunk mains	200 km
Length of distribution mains	820 km
Average operating pressure	40 m
% of time system is pressurised	100% of year
% of total mains length subject to active pressure management	90%
Annual volume of potable water supplied (excluding exports)	13.177 Mm^3/year
Average time from location of mains leaks to shutoff or repair	1 day
Average time from location of service leaks to shutoff or repair	1 day
Leaks on mains (number per 100 km/year)	21/year
Leaks on service connections (number per 1000 connections/year)	22/year
% of system having active leakage control interventions each year	100
Number of water treatment plants	1
Number of pumping stations	10
Number of distribution reservoirs	21
Total number of staff	111
Staff directly involved in water operations	70
Average consumer price	€ 1.00/m^3
Average unit costs of water resource	€ 0.65/m^3
Average unit costs of production and distribution	€ 0.69/m^3
Highest unit cost of production and distribution	€ 0.92/m^3
Energy usage	2.5 million kWh/year

Table 1– Details of the water production and distribution network

Figure 1 shows the potable water supplied by the Water Board of Lemesos for the year 2013. It shows typical annual variations in the consumption pattern, varying from 38,000 m^3/day on average during the winter months of December – January reaching an average of about 50,000 m^3/day in the summer months of June – August.

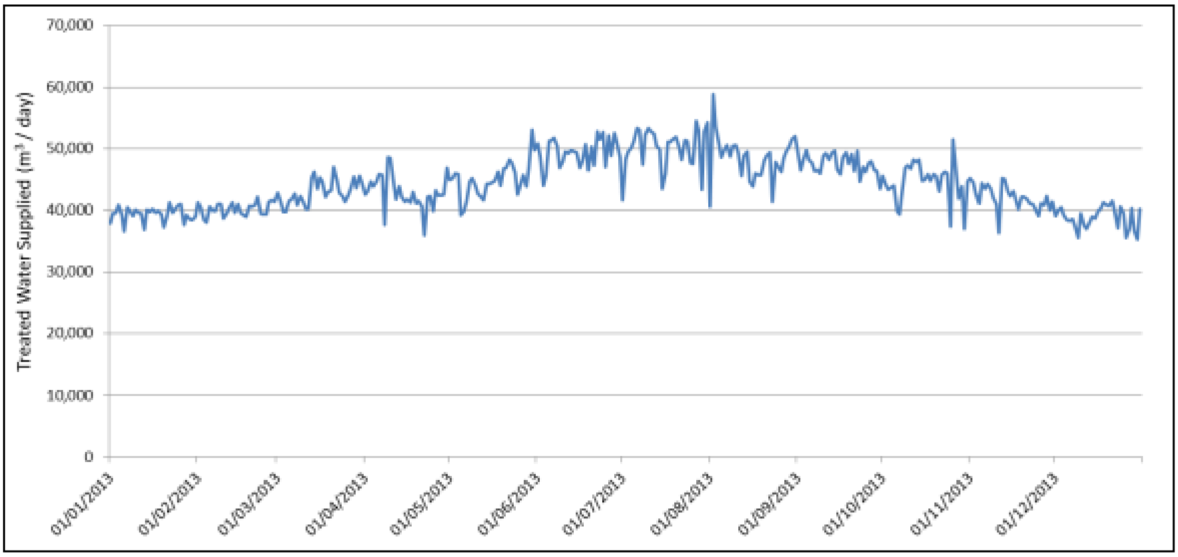


Figure 1` – Water supplied by WBL for the year 2013 in m^3/day.

2 Details context Water Board of Lemesos

Precipitation (460 mm annual average, 1971-2010) is confined to November to May, and often two or three or sometimes up to six consecutive dry years are observed. The water resources of Cyprus have been highly developed with the most economically viable projects already implemented, and further exploitation of remaining scarce water resources will be extremely costly. With this in mind the government has adopted a comprehensive and holistic approach to water management encompassing the conjunctive use of surface and ground water, addressing in parallel the interrelation between domestic and irrigation water demands. Table 2 shows details of the context within which the Water Board of Lemesos is operating.

Relevant factor	Yes	No
Abundant water resources at a basin level?		√
Limited measures required to improve water status to achieve WFD objectives?	√	
River Basin Management Plan (RBMP) completed?	√	
Active quantity management incorporated in the RBMP?	√	
RBMP harmonised with other key socio-economic and land use planning documents prior to adaptation and incl. financing plans?		√
Abundant water resources for water service provider all year every year?		√
Water resources of good chemical quality (low or no treatment)?		√
Water resources located at topographical levels above the level of the customer base (low or no energy costs)?		√
Are the economics of density reasonable (> 20 connections per km)?	√	
Cost effective investment and operating conditions?	√	
Distribution network designed for ease of operation and maintenance without maximum pressure stresses?	√	
Pressure Management implemented throughout the system?	√	
District Metering implemented throughout the system?	√	
Good quality of the network installation (materials selection and workmanship at the time of installation)?	√	
Water pricing limitations?	√	
Conflicting socio-economic needs and/or historical legacy?	√	
Public affordability constrains?	√	
Ability- / willingness-to-pay constraints?	√	
Specific Regulator (Utility subject to regulation)?		√

Table 1 – Specific operational context of the Water Board of Lemesos .

In order to eliminate the dependency of the towns and tourist centres on annual rainfall and in view of the increasing water demand the Government of Cyprus constructed seawater desalination plants serving each town.

Rota cuts had to be implemented in the 1997 to 2000 drought. By 2007, Water Board of Lemesos had reduced leakage to under 92 litres/connection/day (ILI 1.96) by creating additional pressure managed DMAs, but in the 2008 and 2009 drought, water cuts were imposed nationally on irrigation and public water Utilities, and intermittent supply had to be introduced again, despite tankering of water by ship from Athens to maintain reduced domestic supplies.

Cyprus is progressing towards full implementation of the European Union (EU), Water Framework Directive. The EU Water Framework Directive (WFD) sets out the basis for achieving a vision for water management and Cyprus is totally committed to the efficient and effective implementation of its principles and provisions.

3 Overview leakage measures and indicators implemented at WBL

The development of the distribution network took place in an organised fashion with new areas of supply being incorporated into their respective pressure zones, strictly governed by the areas ground contours. Each pressure zone is subdivided into DMAs, a total of 60 are operating, which have a single metered source with physical discontinuity of pipe work at boundaries.

Pressure management has been practically applied to the DMAs with fixed downstream pressure being the basic form of pressure control. Where possible further pressure control has been applied using advanced techniques such as flow modulation, multi-point control or critical point control thus driving leakage to even lower levels.

Leakage interventions are based on Minimum Night Flow monitoring in each DMA prioritising according to the value of water being lost in each DMA and the number of Equivalent Service Pipe Bursts present. Speed and quality of repair policy is such that almost all leaks are fixed on the same day. Interventions are also focused on apparent losses such as meter under registration, stopped meters and illegal connections.

Table 3 shows the measures implemented to assess and reduce leakage as well as the level of leakage and the relevant indicators for the year 2013.

Implemented measure on leakage assessment and reduction	Yes	No
Reliable Bulk Supply Metering	√	
Reliable District Metering	√	
Reliable Customer Metering	√	
Good System Design and Installation	√	
Effective Management of Excess Pressure and Pressure Transients	√	
Speed and quality of repairs	√	
Active Leakage Control at an economic frequency	√	
Sectorisation and/or District Metering Area formation	√	
Asset Renewal: service connections	√	
Asset Renewal: mains	√	
Annual Volume of Real Losses (Level of Leakage, CARL)	**Value**	
2013	2.46 Mm^3/year	
Leakage Indicators used at *Water Board of Lemesos*	**Value**	
Litres per connection per day	127	
ILI	2.5	

Table 3 – Implemented leakage measures and indicators at Water Board of Lemesos.

4 Details strategy, monitoring methods and leakage indicators

The Water Board of Lemesos operates a well-organised water supply system, which is imperative for the proper management of the network. The network zoning and DMA design and the application of pressure reduction has produced favourable results with both background leakage and locatable losses being reduced. Furthermore the frequency of new reported leaks was reduced through the reduction of Pressure Management.

The DMAs vary in size from 50 to 7,000 properties with the average size being approximately 3,000 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 of Lemesos 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 water 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 to meter registration errors.

Distribution of water to the DMAs is effected through dedicated ductile iron mains from the storage reservoirs. Each network zone has its own dedicated storage reservoir supplying the DMAs within the specific 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 meter 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.

In 2002 the Water Board of Lemesos embarked on the redesign of its network management creating smaller and more manageable DMAs with continuous flow and pressure monitoring as well as pressure control. 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 difficulty in working in urban area.

The variation in ground levels across the supply area was examined and particular attention was given to the influence of the pressure within the DMAs. Main highways and physical features 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 continuous monitoring of flow and pressure.

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.

For the effective operation of the DMAs, a reliable continuous monitoring system was established gathering flow data used for Minimum Night Flow (MNF) analysis 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 continuous monitoring of the district meters combines information technology and telecommunication networks to transfer the data via the World Wide Web.

Between 2002 and 2007, leakage was reduced from 138 to 92 litres/connection/day, and ILI from 2.66 to 1.96. During the creation of 14 additional pressure managed DMAs in Pressure Zones 1 and 2 in 2005, WLTF prediction methods for reductions in background leakage were confirmed, and reported leaks were reduced by 45% on mains and 40% on service connections (in line with initial international prediction methods developed by WLTF in 2006).

After intermittent supply had to be used again to combat the water shortages in 2008 and 2009, a detailed post-event analysis of this event was carried out in what is normally a well-managed continuously pressurised distribution system. This has important lessons for any Utility contemplating similar actions in drought. Adverse effects on the distribution system's integrity, leakage levels and costs, are discussed and quantified below.

5 Details proven leakage reduction measure(s)

The leakage reduction measures applied by the Water Board of Lemesos are solely based on the IWA Water Loss Task Force four leakage control strategies to reduce Real Losses, namely: active leakage control, pressure management, speed and quality of repairs and targeted renewal of infrastructure. These had to be balanced in order to achieve the most cost effective leakage programme which reduced leakage to an economically, environmentally and socially acceptable level. This approach is well tested and has been applied around the globe with extremely positive results for utilities.

A permanent leak detection team which focused solely on leak detection activities was established and the latest technology available in leak detection equipment was procured to improve the efficiency of the full time leakage staff in detecting leaks under difficult situations. This equipment included leak noise correlators, leak noise loggers and electronic sounding equipment. Suitable transport for the leakage team was made available. The basic leak detection techniques applied included:

- Locate (Leak noise loggers).
- Localise (Leak noise correlators).
- Pin-point (Ground microphone.

Coupled with the Active Leakage Control the Water Board of Lemesos placed great emphasis in minimising the awareness time of a leak. This was achieved by having a smaller more manageable size DMAs which are continuously flow monitored with data sent on a daily basis to the control centre. As and when leaks are picked up by the Leakage Engineer monitoring the Minimum Night Flows, the Active Leakage Control team is deployed to survey the DMA which takes about 3-4 days on average. This has been an important point in the design of the DMAs, to have continuous flow monitoring and a reasonably small size DMA so that any new leak appearing will be a substantial proportion of the Minimum Night Flow, thus easily recognisable, and a relatively small size DMAs thus locating the leak in a very short period of time.

It should also be emphasised that both the backlog leak detection activities and the permanent Active Leakage Control resulted in the requirement for enhanced leak repair capability. The key to effective leak control was not just the detection of outstanding leaks, but that the leaks were repaired in a timely manner whilst ensuring good quality. Once a burst or leak has been located, the rapid shutoff and repair of the leak is a fundamental aspect of leakage management. To achieve this the Water Board of Lemesos set up a priority procedure for repairing both reported and detected leaks. The target is to repair leaks within 24 hours.

Clearly the quality of materials and workmanship adopted for the repair was also of importance. A poor quality repair will often mean that a leak will re-occur within hours or days of the mains being re-pressurised and effectively, the leak repairs are not sustainable and leaks that are supposedly repaired will continue to run. It was essential that the quality of materials and workmanship employed by the Water Board of Lemesos were of the highest standard.

The physical relationship between leakage flow rates and pressure is well proven. Consequently, by lowering pressure to the absolute minimum required to maintain an adequate level of service to all customers, 20m at the customer’s water meter, within the distribution network, it was possible to reduce the leakage rates from all types of leaks with extremely positive results.

The Water Board of Lemesos replaced old pipelines which were repeatedly presenting problems. The decision to replace pipelines was based on leak clustering data thus targeting the section of the network with the worst record in breaks.

In the longer term, Active Leakage Control procedure at the Water Board of Lemesos includes monitoring of leakage levels in the DMAs. After all the leaks in the DMAs were repaired, a period of monitoring and maintenance began. During this period, the flow into the zone was continually monitored and analysed using software based on Background and Bursts component analysis. Of course it was inevitable that new leaks occurred within the zones and it was necessary at some point to carry out further leak detection surveys and repair exercise.

The point at which subsequent interventions took place was determined separately for each DMA using this method. For each zone, an intervention (entry) level for losses was set and whenever this level was reached due to the natural rate of rise of leakage, a leak detection and repair exercise was carried out to bring the leakage level back down to the original baseline or exit level. The long-term average leakage level for each DMA would lie between the intervention (entry) and exit levels that are set.

This concept of regular intervention into each DMA determined by the setting of intervention (entry) and exit levels would ensure sustainability of the results achieved during the backlog leak detection exercise over a long period of time. It will also ensure that leak detection resources are efficiently utilised in finding leaks in those DMAs where the greatest number of leaks exist and can be found. It will avoid the wasteful allocation of resources to leak detection exercises in DMAs where there may be little or no leakage.

6 Evaluation of further options for pressure management

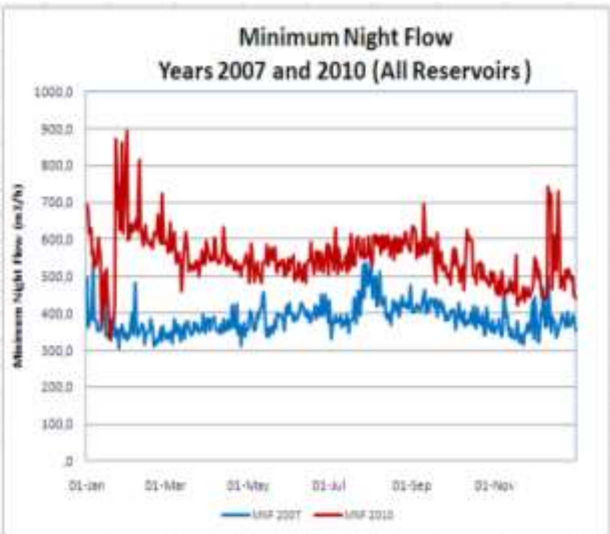
Management of pressure is a key factor in an effective leakage management policy. This has long been recognised by the Water Board of Lemesos and all DMAs are equipped with PRVs to reduce pressure where possible and to control and stabilise pressure in DMAs where pressure reduction is not practicable. Advanced pressure management techniques such as flow and time modulation and critical point control are used with extremely beneficial results. Further pressure management options are now very limited.

7 Results and recommendations

Numbers of reported pipe breaks increased substantially during the period of intermittent supply in 2008 and 2009. A comparison for 20 District Metered Areas showed a trebling of mains breaks and a doubling of service connection repairs between 2007 and 2010, the year after the measures were lifted.

A significant number of unreported breaks, caused by frequent emptying and refilling of the network, did not surface as the network was not pressurized for any significant length of time; nor was there opportunity to locate these by active leakage control without water in the mains. Minimum Night Flow in all DMAs had increased by 164 m^3/hour (see graph).

1 January to 30 December				
	2007	2010	Difference	
Zone 1	5,185,434	5,808,271	622,837	
Zone 2	5,150,320	5,497,431	347,111	
Zone 3	939,659	1,073,681	134,022	
24 Ag.Phila	180,690	152,175	-28,515	
Zone 5	141,591	114,837	-26,754	
Zone 6	83,118	134,086	50,968	
Zone 7	20,759	21,509	750	
Total (m^3)	11,701,571	12,801,990	1,100,419	9.40%
MNF (aver.)	385	549	164	m^3/h (period)
Consumers	60,730	66,684	5,954	
Night use	103	113	10	m^3/h
	392,419	430,892	38,473	m^3 (period)
Background losses & Bursts	5,914	9,149	3,235	m^3 (per day)
	1,969,454	3,046,663	1,077,210	m^3 (period)
	16.83%	23.80%	6.97%	
Night use + Background losses & Bursts	2,361,873	3,477,555	1,115,683	m^3 (period)



The table adjacent to the graph shows that, after adjustment for night use by consumers, the MNF increase represented a 1.08 Mm^3/year (55%) increase in annual leakage. This is more than the annual average volume of water saved (0.80 Mm^3) by intermittent supply during 2008 and 2009.

The Table below provides further evidence to substantiate the increase in leakage caused by the intermittent supply measures. This shows an increase of 12.8% in the System Input Volume for the year 2010 compared with year 2007 without a corresponding increase in customer consumption, which was slightly less than in 2007.

Year	System Input Volume	Customer Consumption
2007: Before Intermittent Supply	Base line 0%	Base line 0%
2008: Intermittent Supply	-17.5%	-9.2%
2009: Intermittent Supply	-9.1%	-8.9%
2010: After Intermittent Supply	+12.8%	-1.2%
2011: Continuous supply	+7.6%	+2.1%
2012:Continuous supply	+5.6%	+2.3%
2013: Continuous supply	+2.0%	+6.0%

Lemesos: System Input Volume vs. Customer Consumption.

The problem of this additional leakage continues to burden the Utility. By 2013, leakage of 127 litres/connection/day had still not fully returned to 2007 levels, and it would not be at all surprising if intermittent supply has increased undetectable background leakage at joints and fittings. So even when the backlog of additional leaks have been found and successfully repaired, the extra leakage caused by the intermittent supply will result in an extra demand on water resources in subsequent years, advancing the onset of the next period of shortage, with a higher base level of leakage in the distribution system.

The implementation of intermittent supply has a direct financial cost to the water utility, which has been assessed as follows for the two years of intermittent supply:

- Loss of revenue due to reduced sales of water: €0.300 million
- Additional costs of staff overtime: €0.365 million
- Cost of repairing additional pipe breaks: €0.325 million

€0.995 million, €0.50 million/year

These short term and relatively easily quantified costs are substantially exceeded by the additional bulk purchase costs (€1.6 million) for the additional post-drought leakage of 1.84 Mm^3 in 2010 to 2013, which only gradually reduces after 2010, but may not disappear completely due to higher background leakage caused by damage to joints and fittings. Consider also that numerous complaints were received from disgruntled consumers regarding quality problems and lack of pressure during intermittent supply. Intermittent supply caused serious disruption and upheaval to daily activities of people whether these were at home or at work, which has not been included in this analysis.

It is evident from the data and information presented in this case study that although intermittent water supply may seem to have been a solution to a water shortage situation in overall terms, the water balance was adversely affected. Supplying less quantity in an intermittent manner causes such deterioration to the network that when continuous supply is re-established additional quantities are lost through increased leakage, which in fact places an added financial burden on the utility.

Intermittent supply operation clearly has a detrimental effect on the integrity of good networks. The amount of water 'saved' is later 'lost' and in greater quantities through increased levels of leakage. Such operational conditions should be avoided especially in systems that have been designed for continuous supply. Over the past 15 years, this and other international experiences by WLTF members have led to the conclusion that it is definitely preferable to operate a distribution system continuously, even at low pressures, than to operate intermittent supply – which has led to the successful implementation of 24x7 policies in India. The fall in ground levels across many Lemesos DMAs limited the use of this option, which has been used in parts of Brazil during drought.

It has also been shown that domestic demand is this case was inelastic and quantities of water saved by customers were very small. Structured conservation programmes, introduced as part of an overall strategy for water conservation, may have achieved better results.

8 References

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