ECONOMIC LEVEL OF REAL WATER LOSSES IN WATER DISTRIBUTION SYSTEM USING MINIMUM NIGHT FLOW STATISTICAL MODEL

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By

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TAHAP EKONOMI TERHADAP KEHILANGAN AIR SEBENAR DALAM SISTEM AGIHAN AIR MENGGUNAKAN MODEL STATISTIK ALIRAN MALAM MINIMUM

Oleh

JABER M. A. ALKASSEH

Tesis yang diserahkan untuk
memenuhi keperluan bagi
Ijazah Doktor Falsafah

Disember, 2013

بسم الله الرحمن الرحيم

﴿ وَقُل رَّبِّ زِدْنِي عِلْمًا ﴾

صدق الله العظيم
سورة طه الاية 114

﴿and say, "My Lord, increase me in knowledge”﴾

From verse 114 of Surat Taha

DEDICATION

Dedicated to, my dear wife for her unlimited love, patience and encouragement; my two children: Razan and Mustafa, whom I left far away (in Gaza, my home town), for their patience and encouragement during this long endeavor; my four children: Izzeddin, Yasmin, Yazan and Ahmed, who stayed with me in Malaysia, for their inspiration, understanding and patience; my brother in-law Mohammed and his wife, for looking after my children in my home town during my study; my brothers, sisters, and all other 'in-law's, for their continued prayers, moral support and encouragement.

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ABI	Annual budget for intervention
AC	Asbestos cement
ADB	Asian Development Bank
ALC	Active leakage control
ANNs	Artificial Neural Networks
ANOVA	One-way analysis of variance
ANU	allowable night user
ANZP	Average night zone pressure
AWER	Association of Water and Energy Research
AWWA	American Water Works Association
AZP	Average zone pressure
BABE	Bursts and background estimates
BPNN	Back propagation neural networks
CARL	Current annual real losses
CI	Cast iron
CI	Cost of intervention
CLMS	Concrete lined mild steel pipe
CNL	Customer night leakage
CON	Number of connections
CV	Variable cost of lost water
DI	Ductile iron
DMA	District metered area
EAVURL	Economic annual volume of unreported real losses
EIF	Economic frequency of intervention

ELL	Economic leakage level
EP	Economic percentage of system
EU	European Union
EURL	Economic unreported real losses
FAVAD	Fixed and Variable Area Discharges
GRNNs	General regression neural networks
GIS	Geographic Information System
HDPE	High-density polyethylene
HZM	Hour Zone Measurement
IWA	International Water Association
IWLTF	IWA Water Losses Task Force
IWMI	International Water Management Institute
LAP	Perak Water Board (Lembaga Air Perak)
LM	Levenberg-Marquardt
MLD	Million Litres per Day
MLPs	Multilayered perceptrons
MLR	Multiple linear regression
MNF	Minimum night flow
MS	Mild steel
MSE	Mean squared error
MWA	Malaysian Water Association
MWIG	Malaysian Water Industry Guide
NC	Night consumption
NN	New Network
NRW	Non-revenue water

NU	Night Use
ON	Old Network
PCA	Principle Component Analysis
PE	Polyethylene
PLC	Passive leakage control
PM	Pressure management
PMA	Pressure management area
PR	Mean of pressure
PRV	Pressure reducing valve
PVC	Polyvinyl chloride
RL	Total pipe length
RM	Ringgit Malaysia
RR	Rate of rise of unreported leakage
SD	Standard deviation
SIS	Sultan Idris Shah
SIV	System input volume
SLR	Simple linear regression
SPAN	National water Services Commission
SPSS	Statistical Package for the Social Sciences
SRELL	Short-run economic leakage level
SSWD	Sacramento Suburban Water District
UARL	Unavoidable annual real losses
UFW	Unaccounted-For Water
UNEP	United Nations Environmental Program
UNL	Utility night leakage

UPVC	Unplasticized polyvinyl chloride
VIF	Variation inflation factor
WDS	Water distribution system
WMA	Weighted mean age of pipe
WWC	World Water Council

LIST OF SYMBOLS

A	A hole of area (m2)
bil	Billion
C_d	A discharge coefficient
D	Pipe diameter
€	Euro
ft	Feet (0.3048 m)
g	The acceleration due to gravity (m2/s)
gal	Gallon (≈ 3.79 L)
Hm^3/year	Cubic hectometers per year = million cubic meters per year
I	Number of input nodes
k	The number of independence variables
km	kilometer
L	Litre
L	Leakage flow rate through a hole of area (L/s)
l/cap/d	litre/cap/day
L/conn/day	Litre/connection/day
L/h	Litre/hour
Lm	Total main length of the network in km
m^3	Cubic meters
mi	Mile (1.60934km)
MLD	Million litres per day
MWh/year	Mega watt hours per year
N1	The leakage exponent
N_c	Total number of service connections

N_h	Number of neurons in the hidden layer
P	Average operating pressure (m)
P	P value
R	Multiple correlation coefficient
r	Pearson’s coefficient of correlation
R^2	Coefficient of multiple determination
s	Second
SSE	Sum of squared errors
S	The average RR of unreported leakage (m^3/d.d)
$	US Dollar
sq. km	Square kilometer
T	Time
V	The volume of the unreported leakage
$\bar{x}$	The mean
Xi	Explanatory variables
Y	Response variable
$\bar{y}$	The mean values of y
y	The observed values of y
$\hat{y}$	The predicted values of y
α	Significance level
β_i	Partial regression coefficients

TAHAP EKONOMI TERHADAP KEHILANGAN AIR SEBENAR DALAM SISTEM AGIHAN AIR MENGGUNAKAN MODEL STATISTIK ALIRAN MALAM MINIMUM

ABSTRAK

Aliran Malam Minimum (AMM) adalah kaedah yang lazim digunakan bagi menyukat kehilangan air di dalam sistem bekalan air. Dalam tahun 2011, purata peratusan air tidak berhasil bagi negeri Perak di Malaysia adalah pada kadar 30.4%, suatu jumlah yang menyumbang kepada kerugian besar dari segi kewangan, bekalan dan tekanan air, dan ia juga merupakan penggunaan tenaga yang besar. Bagi kajian ini, suatu julat masa yang bersesuaian bagi AMM serta kehilangan sebenar air atau kadar NRW, bagi daerah Kinta di Negeri Perak, Malaysia telah dikaji selidik. Aliran dan tekanan bagi 361 zon telah dipantau bagi tempoh 24 jam oleh Lembaga Air Perak (LAP) dengan menggunakan perisian PrimeWorks (versi 1.5.57.0). Sembilan puluh (90) daripada 361 zon kajian telah dipilih secara rawak. 90 zon kajian ini kemudian dibahagikan kepada tiga kumpulan, dengan setiap kumpulan mempunyai 30 zon. Data nilai minimum aliran air bagi tahun 2010 telah disaring mengikut julat masa di antara jam 1.00 pagi sehingga 5.00 pagi. Frekuensi kekerapan data AMM dianalisis setiap 15 minit. Hasil kajian menunjukkan, majoriti sebanyak 85% daripada frekuensi AMM di 90 kawasan kajian terjadi dalam tempoh masa antara jam 2.30 pagi sehingga 4.30 pagi, manakala 95% daripada frekuensi tersebut mengambil tempat dari jam 1.45 pagi sehingga 4.45 pagi. Ia menunjukkan kejadian AMM bagi setiap zon pada tahun 2010 dianggarkan berlaku dari jam 1.00 pagi sehingga 5.00 pagi. Oleh itu, suatu analisis statistik rangkaian agihan air dan ujian model AMM telah dijalankan untuk tujuan menganggarkan jumlah kehilangan air di

daerah Kinta, Perak. Faktor-faktor fizikal, hidraulik dan faktor bolehubah operasi telah dipilih dan dikaitkan dengan terjadinya AMM (L/s). Kaedah statistik regresi linear berganda (MLR) telah diguna pakai bagi tujuan menentukan faktor-faktor yang menyumbang kepada AMM (L/s). Hasilnya, didapati bilangan sambungan, panjang paip (meter) dan tempoh penggunaan paip (tahun) adalah penyumbang utama kepada terjadinya AMM (L/s).

Kelebihan kajian ini berbanding kajian-kajian yang terdahulu dapat dilihat dari aspek model yang telah dibangunkan bagi mengenal pasti akibat daripada setiap daripada faktor yang menyebabkan kehilangan air. Perbandingan di antara analisis MLR dan rangkaian neural buatan (ANNs) telah diguna pakai bagi menilai pencapaian model-model yang telah dibangunkan. Hasil ujian perbandingan ujian t-berpasangan menunjukkan bahawa nilai p (nilai p adalah 0.573) tidak begitu signifikan. Oleh kerana itu, model yang dibangunkan tidak memberi kesan signifikan dari segi statistik, dan ini menunjukkan kepada suatu kesimpulan bahawa tiada perbezaan dapat dikesan di dalam jangkaan bacaan AMM (L/s) akibat daripada pembalikan regresi serta ANNS, dan kedua-dua kaedah tersebut didapati berfungsi dengan baik. Justeru, nilai R^2 untuk pembalikan dan model rangkaian neural buatan adalah pada kadar 0.605 dan 0.672. Pada masa ini, belum ada kajian dibuat bagi mengenal pasti aras bocor ekonomi (ELL) bagi LAP di dalam mana-mana kajian sebelum ini. Justeru, kajian ini adalah suatu inisiatif bagi membangunkan suatu garis panduan berkenaan operasi pengawalan tahap ekonomi air tidak berhasil bagi daerah Kinta, untuk tujuan meminimumkan kebocoran di dalam sistem bekalan air. Anggaran kehilangan air untuk kes ketirisan dan kebocoran yang dilaporkan boleh dikira menggunakan perisian PrimeWorks. Kehilangan sebenar/ketara pula disukat menggunakan teori campur tangan ekonomi *(economic intervention theory)* dan

analisis pembalikan, bagi tujuan menganggarkan purata kadar kenaikan kebocoran yang tidak dilaporkan. 97% dari jumlah pembaikan paip yang didaftarkan dalam tahun 2010 telah dijalankan ke atas paip yang mempunyai ukuran diameter kecil, yakni kurang dari 50mm. Paip-paip dalam saiz ini lazimnya digunakan sebagai paip servis dan paip komunikasi. Hasil kajian ini juga menunjukkan bahawa aras bocor ekonomi jangka pendek (SRELL) dijangkakan pada kadar 17.99 liter/sambungan / hari, atau 2.0 m^3/km paip utama/hari. Hasil kajian ini membentangkan suatu penambahbaikan yang lebih berkesan di dalam pengurusan sistem bekalan air, yang memberi kesan signifikan dari segi kewangan, penjagaan alam sekitar dan kepentingan sosial bersama.

ECONOMIC LEVEL OF REAL WATER LOSSES IN WATER DISTRIBUTION SYSTEM USING MINIMUM NIGHT FLOW STATISTICAL MODEL

ABSTRACT

Minimum night flow (MNF) is a common method used to evaluate water loss in a water network. In 2011, the average percentage of non-revenue water (NRW) for the state of Perak in Malaysia was 30.4 %, a figure which resulted in major financial, supply, and pressure losses, as well as excessive energy consumption. In this study, the appropriate time band of MNF and the actual water loss or amount of NRW for the district of Kinta in Perak, Malaysia were investigated. Flow and pressure for 361 zones were monitored for 24 h by the Perak Water Board (Lembaga Air Perak, LAP) using PrimeWorks software (version: 1.5.57.0). Ninety study zones were randomly selected from 361 zones. The 90 study zones were divided into three groups, with each group having 30 zones. Data on the minimum value of flow in 2010 were screened within the time band of 1:00 am to 5:00 am. The frequency of MNF occurrences was analysed every 15 minutes. Results of the study revealed that the majority (85%) of MNF frequencies in the 90 study areas were found at the time band 2:30 am to 4:30 am, whereas 95% of the frequencies were at time band 1:45 am to 4:45 am; therefore, the mean MNF for each zone in 2010 was determined to be between 1:00 am and 5:00 am. Furthermore, a statistical analysis of the characteristic of water distribution network and a modelling of MNF were carried out to estimate water loss in Kinta District, Perak. Factors for physical, hydraulic, and operational variables were selected and correlated with MNF (L/s). Multiple linear regression (MLR) was used as a statistical technique to determine factors that contributed to

MNF (L/s). Consequently, number of connections, pipe length (m) and pipe age (year) were the main contributors to MNF (L/s).The advantage of the present study over the past studies is that the models developed were able to determine the contribution of each factor of water loss. Comparisons of MLR analyses with Artificial Neural Networks (ANNs) have been applied to evaluate the performance of developed models. The output of the paired t-test showed that p value (p value 0.573) was not significant. Thus, the model was not statistically significant, which suggests that no differences were observed in the predictions of MNF (L/s) from regression and ANNs and both techniques are performing equally well. Hence, R^2 values for regression and neural networks models are 0.605 and 0.672, respectively. Currently, there is no study taken to determine the economic leakage level (ELL) for LAP in the study area. Thus, this study has taken the initiative to estimate the economic level of non-revenue water operational control in Kinta district for minimising leakage in water supply system. The estimated water loss for reported leaks and bursts can be calculated using PrimeWorks software. Unreported real losses are calculated using economic intervention theory and regression analysis to estimate the average rate of rise of unreported leakage. About 97 % of the registered pipe repairs in 2010 were conducted on pipes with small diameters fewer than 50 mm. Pipes within this size range are usually used as service pipes and service connections. Results of the study revealed that short-run economic leakage level (SRELL) will be around 17.88 litres/service connection /day or 2.0 m^3/km mains/day. The research results show an effective improvement in the management of water distribution systems (WDSs), which could result in financial, environmental and social benefits.

CHAPTER 1-
INTRODUCTION

1.1 Background of the study

Water losses occurring in water distribution systems (WDSs) are now considered as a serious problem, necessitating a robust and effective management strategy (Kanakoudis and Tsitsifli, 2010a). Approximately, one third of total abstracted water for urban uses is either lost because of leaks and pipe bursts occurring in WDSs, or not included in revenue and financing systems (Klein, 2008; Mounce *et al.*, 2010). Water losses are occurring in both developed and developing countries throughout the world (Thornton *et al.*, 2008). Estimated NRW levels for developed and developing countries were 15 % and 35 % of the annual system input volume, respectively (Kanakoudis and Tsitsifli, 2012). A large percentage of water loss in distribution networks is common in many Asian cities, averaging 35% and even reaching much higher levels (Frauendorfer *et al.*, 2010).

In Malaysia, according to Malaysian Water Industry Guide (MWIG, 2012), the average percentages of NRW in Malaysia and in the state of Perak in 2011 were 36.7 % and 30.4 %, respectively. The total volume of treated water loss has recorded 1.94 billion cubic meters (m^3) and 123.03 million m^3, respectively. These average percentages have led to lower income generation which could create constraints on maintenance and operation of water reticulation systems (Frauendorfer *et al.*, 2010). Moreover, water losses not only have economic and environment aspects but also public health and social impacts. Often, leakage leads to service interruption, is costly in terms of energy losses as well as may cause water quality contamination via pathogen intrusion (Mutikanga and Sharma, 2012). NRW control has been given a high priority issue by the Malaysian Government. For example, in the Eighth

Malaysian Plan, a total of RM (Ringgit Malaysia) 640 million was expended to reduce the NRW; the activities involved the replacement of old pipes and old water meters, reduction of water pilferages, and the rehabilitation and upgrading of WDSs (Ku-Mahamud *et al.*, 2007a).

Leakage is one of the major contributors to water loss in WDSs, which means that major amounts of water and revenue are being lost, forcing water utilities to develop effective water loss and NRW reduction strategies (Kanakoudis and Tsitsifli, 2010a). Leakage from a WDS can be determined by adopting several approaches. In the context of WDS operation and management, the sectorisation of large networks (division in district metered areas or DMAs) can evaluate leakage level in each DMA, allowing leakage location activities to be directed to the worst parts of the system, thus increasing their efficiency (Crowder *et al.*, 2012; Gomes *et al.*, 2012). The introduction of DMAs and pressure management areas (PMAs) can achieve significant reduction in real losses and frequency of bursts (Fantozzi et al., 2009). To estimate leakage levels in a water network, minimum night flow (MNF) can be an indicator of distribution leakage and is considered to be the major contributor to cost-effective and efficient leakage management (García *et al.*, 2006; Farley, 2012; Loureiro *et al.*, 2012).

1.2 Problem statement

Nowadays, more than developing new resources, optimal use of water is considered by improving operational management of WDSs. In WDSs, a considerable part of supplied water is unused because of water losses (Nazif *et al.*, 2010). Basically, water loss is a part of non-revenue water (NRW), whereas water losses in a WDS consist of real losses and apparent losses. Real losses are mainly due to leakage from service connections, joints in water pipes, pipe bursts, pipe cracks and overflows from storage tanks, whereas apparent losses are produced by illegal water consumption and inaccurate customer metering (Farley and Trow, 2003; Karadirek *et al.*, 2012). The problem of excessive water losses from WDSs is common in many countries such as Malaysia. Beginning from the Sixth Malaysian Plan, NRW control program has shown a major reduction of NRW. For example, in the Ninth Malaysia Plan, RM 1.09 billion is budgeted to reduce the NRW from 38% (2007) to 30% (2011), and to improve the efficiency of water supply (Ku-Mahamud *et al.*, 2007b). The MWIG (2012) reported that the average percentage of NRW in Malaysia in 2010 was 36.4% and the total water loss amount was 1.87 billion m^3. The National Water Services Commission (SPAN) stated that 25% NRW target can be achieved way before 2020 (AWER, 2012).

Furthermore, most states experience high NRW and this problem is more serious in some states than in others (Lee, 2005; Lee, 2007; Munisamy, 2009). For example, Perak, one of the 14 states of Malaysia (Gazzaz *et al.*, 2012b), has also experienced high level of NRW. Previous research shows that the NRW percentage for Perak from year 2001 until 2004 is reduced from 37.2% to 31.7%, while in 2005 to 2006; the percentage slightly increases from 30.6% to 30.7% (Adlan *et al.*, 2009), as shown in Table 1.1. Table 1.1 summarises the average percentages of NRW in Perak (Lee, 2005; Lee, 2007; Adlan *et al.*, 2009; MWIG, 2011; MWIG, 2012). The average percentages of NRW in the state of Perak in 2010 and 2011 were 29.4% and 30.4%, respectively, ranking No. 5 of the 14 states in 2011. The estimated annual volume of NRW was in the order of 116.14 and 123.03 million m^3 in 2010 and 2011, respectively (MWIG, 2012).

Table 1.1: The average percentages of NRW in Perak

Year	**% NRW, Perak**	**Reference**
2001	37.2%	Adlan *et al.* (2009)
2002	30.2%	Lee (2005)
2003	30.2%	Lee (2007)
2004	31.7%	Adlan *et al.* (2009)
2005	30.6%	Adlan *et al.* (2009)
2006	30.7%	Adlan *et al.* (2009)
2009	30.7%	MWIG (2011)
2010	29.4%	MWIG (2011)
2011	30.4%	MWIG (2012)

Consequently, high levels of NRW represent huge volumes of water being lost and affect the financial capability of water utilities through lost revenues and increased operational costs (Kingdom *et al.*, 2006). Furthermore, NRW is a good indicative of water utility performance; high levels of NRW usually indicate a poorly managed water utility (Frauendorfer *et al.*, 2010). Significant amounts of water loss is being lost because of leakage in WDSs (Kanakoudis and Tsitsifli, 2010a). The large volume of water leakage can also cause contaminant intrusion under low- or negative-pressure conditions within pipes, which may lead to harmful or even serious water quality incidents (Boulos and AbouJaoude, 2011; Mutikanga and Sharma, 2012). On the other hand, financial, environmental, and social benefits can be derived from controlling and improving management of water losses caused by leakage (Uyak *et al.*, 2007; Kanakoudis *et al.*, 2011b). Hence, minimising water lost through leakage from water supply systems is one of the main challenges that faced water network managers. Significant amounts of money must be invested every year for leak detection and repairs. This investment will be balanced by the benefits resulting from the use of recovered water from repaired leaks (Delgado-Galván *et al.*, 2010).

Water losses vary among systems and can be attributed to a number of different factors. These factors include network length, number of service connections, pressure fluctuation over the day, pipe material, leaks, bursts, and age of the system (Uyak *et al.*, 2007; Gomes *et al.*, 2011). Water losses can be either real (physical) losses or apparent losses and real losses generally represent the majority of water loss. (Kanakoudis and Tsitsifli, 2012). To estimate real losses, MNF can be an indicator of distribution leakage and consumer wastage (Johnson *et al.*, 2009). The technique of MNF monitoring to identify areas of leakage is considered to be the major contributor to cost-effective and efficient leakage management. (García *et al.*, 2006; Farley, 2012).

In general, most of the research studies estimated water losses in water distribution networks by applying the International Water Association (IWA) Water Balance and MNF analyses combined with hydraulic simulation models (such as EPANET and GIS models) (Tabesh *et al.*, 2009; Cheung *et al.*, 2010; Karadirek *et al.*, 2012) and developing an empirical model for estimating background leakage rates (Hunaidi, 2010). Other studies proposed statistical modelling to predict variations in pipe bursts rates in water main pipes (Shamir and Howard, 1979; Kettler and Goulter, 1985; Kanakoudis and Tolikas, 2001; Cannarozzo *et al.*, 2006). However, all reviewed statistical applications were focused on developing models that predict pipe bursts as a function of several variables, such as pipe age, type, and diameter; and occurrence of previous bursts. Previous models did not consider the number of connections and the pressure.

In this study, modelling of MNF was carried out to estimate leakage in Kinta District, Perak. Several factors for physical, hydraulic, and operational variables were selected. The detailed contribution of each factor to leakage was not fully clarified in previous studies. Considering this gap and using statistical analysis, the present study aims to determine the contributions of major factors that affect leakage in a water supply network in Malaysia (Kinta District, Perak State). Hence, the models developed in terms of predictor variables may conveniently be applied in the regions selected for the present study and, in the regions with similar WDSs.

The water supply in the state of Perak is managed by the Perak Water Board (Lembaga Air Perak, LAP) which was formed under the state legislation. LAP has the goal to supply clean water for the needs of the population, both urban and rural, and the requirements for commerce and industry. Currently, there is no study taken to determine the economic leakage control level for the LAP, Perak, Malaysian water network. As such resources may have been spent without specific economical limit for leakage reduction. Nevertheless these unending studies need to be strategised so that economic level of leakages control could be obtained and leakages management could be developed. This study also aims to estimate the economic level of leakage for water operational control in Kinta district to minimise leakage in water supply system and to achieve better management of water losses. Consequently, the research results show an effective improvement in the management of WDSs, which could result in financial, environmental and social benefits.

1.3 Objectives of Research:

This research was planned and executed based on the following objectives:

1. To investigate the appropriate time band of MNF and to determine the MNF (L/s), and the real water loss for the selected DMAs.
2. To determine the major factors affecting water loss in a water supply network using statistical analysis, and to evaluate the final prediction model of the relationship of the factors that contributed to the MNF (L/s) using multiple linear regression (MLR)
3. To compare the regression model with Artificial Neural Networks (ANNs).
4. To estimate the economic leakage level (ELL) using economic intervention approach.

1.4 Scope of study

Flow and pressure for 361 zones in Kinta district were monitored for 24 h by the Perak Water Board (Lembaga Air Perak, LAP) using PrimeWorks software (version: 1.5.57.0). A total of 90 DMAs out of 361 DMAs were randomly selected. The 90 study zones were divided into three groups, with each group having 30 zones. By using ‘PrimeWorks’, data on flow and pressure for the 90 DMAs in 2010 were collected from the records of the water network in the study areas. Screening of recorded data of MNF (L/s) for 90 DMAs in the time interval between 1:00 – 5:00 am was carried out, and the frequency of time of MNF (L/s) was analysed.

Generally, water losses vary from system to system and are influenced by a number of factors, including network length, number of service connections, pressure fluctuations throughout the day, pipe material, and age of the system. According to the LAP, the characteristics of the pipe networks for particular DMAs were identified; mainly, the total length of pipe network (meter), number of connections, age of pipes (year), and type of reticulation pipe. In order to estimate leakage in a WDS in the study area, statistical analyses of the water distribution network and modelling of MNF were carried out. Numerous statistical techniques were applied for modelling of MNF to estimate real losses in Kinta District, Perak. To evaluate the results of the linear regression models, neural network models were developed to forecast the MNF (L/s). Comparisons of MLR analyses with Artificial Neural Networks (ANNs) have been applied to evaluate the performance of developed models.

Leakage in WDSs is an important issue which is affecting water companies and their customers. Many utilities have developed strategies to reduce water losses to an economic or acceptable level. The economic level of leakage (ELL) can be predicted using bursts and background estimates (BABE) component analysis models. Based on the concepts of BABE, real losses consist of background leakage (flow rate less than 0.5 m3/h), reported leaks and bursts, and unreported leaks and bursts. For a policy of regular survey, at current operating pressure, the three components of short-run economic leakage level (SRELL) can be calculated using the economic intervention concept. Thereupon, the real losses from reported bursts are estimated from number of reported burst repairs; background (undetectable) leakage is evaluated as a multiple of unavoidable background leakage as well as economic annual volume of unreported real losses is determined using economic intervention theory. Consequently, the SRELL at current operating pressure for the present system is estimated.

1.5 Layout of the Thesis

The present thesis is organised in five chapters. A brief outline of the structure is given below.

Chapter 1 **Introduction:** This chapter introduces the background of the study and provides insight into the problem of water distribution loss and highlights the importance of water loss management. It also gives a short overview of the problem statement and objectives of research.

Chapter 2 **Literature review:** This chapter gives an overview of the magnitude of water losses in both the developing and developed countries and specifically for Malaysia with emphasis on the water supply network in Kinta District, Perak State. It presents a comprehensive review of the state-of-the-art of methods and tools applied for water loss management in WDSs, and the major factors that affect water loss in a water supply network in Kinta District. In addition, it highlights the advantage of applications of Artificial Neural Networks (ANNs) in prediction of the water resources system. Lastly, to improve the efficiency of WDS in Kinta District and to reduce water loss, the benefits of the economic intervention concept is also focussed on.

Chapter 3 **Study area & Methodology:** This chapter represents details of data collection for a total of 90 DMAs out of 361 DMAs randomly selected. The procedure to determine the appropriate time band of MNF and water loss in the Perak, Malaysian water network was fully described using PrimeWorks. It highlights the characteristics of the pipe networks for particular DMA synchronised to be consistent with the LAP. It also describes the statistical techniques for analysis of the water distribution network and modelling of MNF (L/s). Also, it introduces the application of ANNs to forecast the MNF (L/s). Finally, it provides a practical method for calculating economic leakage levels (ELL).

Chapter 4 **Results and Discussion:** This chapter presents the results of the data analysis and discusses the main finding of the study. The period of MNF (L/s) as between 1:00 am and 5:00 am was identified. The procedure how to arrive to this conclusion was fully described. Data analysis on the main characteristics of the pipe networks was carried out and extensively discussed. Using statistical analysis, the detailed contribution of each factor to MNF (L/s) was fully clarified. Comparisons of MLR and ANN techniques have been used to evaluate the performance of developed models. For a policy of regular survey, at current operating pressure, the economic intervention concept for the calculation of the three components of short-run economic leakage level (SRELL) was included.

Chapter 5 **Conclusions and recommendations:** The closing chapter outlines the major findings and conclusions of the research and offers some recommendations for future research.

CHAPTER 2 -
LITERATURE REVIEW

2.1 Introduction

Globally, many water utilities specifically in developing countries continue to operate WDSs with significant amount of water and revenues losses. There are various factors that contribute to water losses such as ageing infrastructure, high pressure, network length etc. Hence, many tools and methods for minimising water loss in the distribution system have been developed and applied over the years. The management of water losses requires understanding why, where and how much water is lost, and developing appropriate intervention measures. This chapter highlights and reviews the existing methods and tools for water loss management, and identifies the research knowledge gaps.

2.2 Non-revenue water (NRW)

Water is the world's most valuable elements and one of the main sources for life (Ku-Mahamud *et al.*, 2005). The growing pressure on water has led this resource to be considered scarce and therefore, the efficient management of water resources is a growing necessity (Farley *et al.*, 2008; Farley *et al.*, 2010; Gonzalez-Gomez *et al.*, 2011; Mutikanga and Sharma, 2012). With increasing global changes such as climate change, urbanization and population growth, there is a high probability of an additional reduction in the available water resources in the future (Adamowski and Karapataki, 2010; Nikolic *et al.*, 2013; Tan *et al.*, 2013). This could be combined by the high rate of water infrastructure deterioration which would cause greater loss of treated and pressurized drinking water. Besides, the impact of poorly managed urban

WDSs associated with the global change could result in extreme scarcity scenarios (Babovic *et al.*, 2002; Thornton *et al.*, 2008; Mounce *et al.*, 2010; Mutikanga *et al.*, 2012). Nowadays, many international organizations such as International Water Management Institute (IWMI), The International Water Association (IWA) and World Water Council (WWC) are set up to organise and monitor global water management (Ku-Mahamud *et al.*, 2005). One of the most important issues affecting water utilities, especially in urban areas in the developing countries, is the considerable difference between the volume of water flow into the distribution system and the volume of water billed to consumers which is called "non-revenue water" (Kingdom *et al.*, 2006; Koelbl *et al.*, 2009b). In the year 2000, the IWA and American Water Works Association (AWWA) recommended water utilities and drinking water stakeholders to use the term NRW (AWWA, 2009). The expression "water loss" and "non-revenue water" are now internationally accepted, and have replaced expression such as "Unaccounted-For Water" (UFW) (Farley and Trow, 2003; Brothers, 2005; McKenzie and Seago, 2005; Çakmakcı *et al.*, 2007; Frauendorfer *et al.*, 2010).

2.3 Water loss – a global problem

2.3.1 NRW levels in developed and developing countries

Water loss is considered as a global problem and major issue in water management that requires a solid and effective management strategy (Koelbl *et al.*, 2009a; Wyatt, 2010; Kanakoudis and Tsitsifli, 2010a; Kanakoudis and Tsitsifli, 2010b). Approximately one-third of total abstracted water for urban uses is either lost due to leaks and pipe bursts occurring in water distribution systems (WDSs), or not included in revenue and financing systems (Cabrera *et al.*, 1995; Kanakoudis and

Tolikas, 2001; Hunaidi *et al.*, 2004; Klein, 2008; Mounce *et al.*, 2010; Nazif *et al.*, 2010). Water loss in many countries worldwide can be as high as 50% of the water input in the system (Lambert, 2002; Hunaidi *et al.*, 2004; Çakmakcı *et al.*, 2007; Öztürk *et al.*, 2007; Uyak *et al.*, 2007; Puust *et al.*, 2010; Kanakoudis *et al.*, 2012; Palau *et al.*, 2012). Water losses are occurring in both developed and developing countries (McKenzie and Seago, 2005; Gurría, 2007; Thornton *et al.*, 2008; Gonzalez-Gomez *et al.*, 2011) with an estimated NRW levels of 15% and 35% of the annual system input volume, respectively (Kingdom *et al.*, 2006; Gonzalez-Gomez *et al.*, 2011; Kanakoudis and Tsitsifli, 2012; Al-Omari, 2013).

The Global Water Supply and Sanitation Assessment 2000 Report pointed out that NRW levels in Africa, Asia, Latin America and the Caribbean, and North America are 39%, 42%, 42%, and 15%, respectively (WHO-UNICEF-WSSCC, 2000; Islam *et al.*, 2011). Moreover, the average water loss in European Union (EU) countries is about 20%, whereas several countries have water loss levels lower than 10% such as Germany and Denmark (Colombo and Karney, 2002; Çakmakcı *et al.*, 2007; Öztürk *et al.*, 2007; Puust *et al.*, 2010). A pipe network with NRW less than 15% is supposed to be in good condition. If the value of NRW is greater than 30% the network needs immediate inspection (Kanakoudis, 2004a). The Word Bank estimates the world wide NRW volume to be 48.6 billion m^3/year and the real losses volume (40%) occurring in the developing countries is sufficient to supply approximately 200 million people. Furthermore, the Word Bank estimates the monetary value of the global annual NRW volume to be US $ 14.6 billion per year (Kingdom *et al.*, 2006; Thornton *et al.*, 2008; Kanakoudis and Tsitsifli, 2012).

2.3.2 NRW levels in Asia

A large proportion of water loss in distribution networks is common in many Asian cities, averaging 35% in the region's cities and even reaching much higher levels (Frauendorfer *et al.*, 2010). A recent report by the Asian Development Bank (ADB) pointed out that NRW levels in 47 water utility systems across Indonesia, Malaysia, Thailand, the Philippines, and Vietnam, make up an average of 30% of water produced, with wide variations among individual utilities ranging from 4% (PUB, Singapore) to 65% (Maynilad, Manila) (Kingdom *et al.*, 2006; Mutikanga and Sharma, 2012).

2.3.3 NRW levels in Malaysia

2.3.3.1 Introduction

Water loss in WDSs is now an issue of growing importance, and much effort is being made to ensure the sustainability of these public services (Gomes *et al.*, 2011). The problem of excessive water losses from water supply distribution networks is common in Malaysia. The effort to reduce the NRW is to be continued in the Ninth Malaysia Plan in order to improve the efficiency of water supply (Ku-Mahamud *et al.*, 2007b). According to the Association of Water and Energy Research Malaysia (AWER, 2012), the National Water Services Commission (SPAN) reported that 25% NRW target can be achieved way before 2020.

2.3.3.2 Water Supply in Malaysia

Malaysia is located between 1° to 7° in North latitude and 100° to 120° in East longitude within the equatorial zone. Malaysia consists of Peninsular Malaysia

(West Malaysia) and the island of Borneo, namely Sabah and Sarawak (East Malaysia) (Ho, 1996; Kubota and Ahmad, 2006; Mekhilef, 2010; Shafie *et al.*, 2011; Mekhilef *et al.*, 2012). The total land area of Malaysia is about 330,000 sq. km. Almost 60% is made up of East Malaysia and the remaining 40% is occupied by the Peninsular Malaysia. About 76% of the total population is concentrated in Peninsular Malaysia (Ong *et al.*, 2011; Shafie *et al.*, 2011; Mekhilef *et al.*, 2012). In 2009, the population of Malaysia was 25.4 million, by 2020 the population is expected to be almost double with reference to 1980. The percentage of population growth is less than 3% annually (Shafie *et al.*, 2011). Malaysia has a population of 27.73 million based on the census in 2008 (Ong *et al.*, 2011). The national population was 29.6 million in 2012 (Akrami *et al.*, 2013).

Malaysia's location ensures that the country has a fairly abundant amount of water resources. On average, monthly rainfall in the country varies from 190mm to as high as 450mm in some states during the heavy rainy season, and the estimated annual rainfall volume is about 990 km^3, of which 36 % (or 360 km^3) are lost to evapotranspiration. Water resources are fairly equally distributed across the different states in the country (Lee, 2007).

Water services in Malaysia cover both water supply and sewerage services. Water supply services comprise three categories: (i) the abstraction of water from dams and rivers or aquifer, (ii) the treatment of water extracted to make it usable and (iii) the distribution of treated water from the water treatment plants to the consumer. In 2000, the Malaysian Water Association (MWA) took the initiative of collecting the data and information statistics of the performance indicators of water utilities and publishing them in the annual Malaysia Water Industry Guide. The performance indicators include physical, operational, service and financial performance indicators.

(Munisamy, 2009). The water supply services are managed and operated by both state authority and concession companies. In Perak, water supply services are managed by the Perak Water Board (Lembaga Air Perak, LAP) which is owned by the state government (Lee, 2005; Lee, 2007; Ong *et al.*, 2007).

About 97% of Malaysia’s water supply comes from rivers (Chan, 2012). The method of direct extraction from rivers is the main source of raw water, accounting for two third of raw water supply in the country, followed by storage dams and groundwater (Lee, 2007). The total production of raw water resources in 2009 and 2010 were 14,671 Million Litres per Day (MLD) and 15,098 MLD, respectively, excluding raw water from treated water supply from private operators (MWIG, 2011). In 2011, the total production of raw water resources was 15,509 MLD (MWIG, 2012). The water supply design capacity and production has increased rapidly for the past 20 years. During the period 1981-2002, the design capacity raised at an average rate of 7.9 % per annum while production raised at a rate of 7.6 % per annum (Lee, 2005). In 2009, the treatment plants’ design capacity and production were 16,403 MLD and 13,495 MLD, respectively, accounting the production reverse margin as 17.7%. By 2010, the treatment plants’ design capacity and production reached 16,771 MLD and 14,065 MLD, respectively, creating the production reverse margin to be 16.1% (MWIG, 2011). According to MWIG (2012), the treatment plants’ design capacity and production in 2011 were 17,421 MLD and 14,564 MLD, respectively, generating the production reverse margin to be 16.4%.

In the Eighth Malaysia Plan, the government’s development expenditure for the infrastructure sector was about RM39.7 billion. Of these, 12.1 % was allocated to water supply, mainly for capital expenditures such as the construction of dams, new treatment plants, the rehabilitation and upgrading of treatment plants as well as distribution systems (Lee, 2007). The importance of conservation of water in distribution systems has been practiced since 1980s (Adlan *et al.*, 2009). Controlling and reducing NRW are on high priority in the agenda of the Malaysian Government (Ku-Mahamud *et al.*, 2005). Hence, a total of RM640 million was expended in the Eighth Malaysia Plan to reduce the NRW and RM 1,088.3 millions was budgeted in the Ninth Malaysia Plan, to reduce the NRW from 38% (2007) to 30% (2011) (Ku-Mahamud *et al.*, 2007b). In 2010, the average percentage of NRW for Malaysia was 36.4%. In 2011, the state of Pulau Pinang was considered to be the lowest level of NRW with 18.4% and the state of Perlis was the highest levels of NRW with 59.8% (MWIG, 2012). However, SPAN is still standing on the proposed target of 25% national NRW level by 2020 (AWER, 2012).

2.3.3.3 State of Perak-District of Kinta

The study area is situated in the Kinta district which is one of the 10 administrative districts of the state of Perak. Perak is one of the 14 states of Malaysia (Gazzaz *et al.*, 2012b). Perak is considered as the second largest state in Peninsular Malaysia in terms of land area (21,006 km^2). It is surrounded by Kedah and the Thai state of Yala from the north, Penang from the northwest, Malacca Strait from the west, Selangor from the south, and Kelantan and Pahang from the east. The population of Perak was about 2.249 million in 2010 and is projected by the Structure Plan of Perak State to become 2.676 million in the year 2020. Ipoh city is the capital of Perak which is in Kinta District (Gazzaz *et al.*, 2012a); Figure 2.1 shows the state of Perak and District of Kinta.

Ipoh (4.57°N, 101.1°E) is the fourth largest city in Malaysia with a population of 702,464 (2009) and ranking in 2007 as sixth most populous urban centre in Malaysia (Ishak *et al.*, 2011). In Ipoh, Kinta River is the most important water resource for drinking and irrigation and the second main water resource in Perak. It is the major stream of Perak River, which is the fundamental source of drinking and irrigation water in Perak (Gazzaz *et al.*, 2012a; Gazzaz *et al.*, 2012b). Direct extraction from rivers is the main source of raw water (Lee, 2007). In 2010, the MWIG (2011) reported that 884 MLD of total 1,331 MLD was directly extracted from Perak River, followed by storage dams (447 MLD). The treatment plants' design capacity and production were 1,726 MLD and 1,080 MLD, respectively, amounting production reverse margin 37.4%. By 2011, about 878 MLD of total 1,354 MLD was directly extracted from Perak River, followed by storage dams (476 MLD). The treatment plants' design capacity and production were 1,740 MLD and 1,109 MLD, respectively, making production reverse margin 36.3% (MWIG, 2012).

Figure 2.1: Kinta district, Perak

In 2010, the MWIG (2011) stated that about 99.2 % of the Perak's population has access to water supply, including urban area (100%) and rural area (98.0%). The total water consumption was 762 MLD, consisting of domestic consumption (72.4%) and non-domestic consumption (27.6%). Domestic consumption per capita was 228 litre/cap/day, ranking No. 6 of 14 States, after Pulau Pinang (291 L/cap/d), Perlis (257 L/cap/d), Selangor (239 L/cap/d), Kedah (235 L/cap/d) and Melaka (231 L/cap/d). The number of connections was 665,674 (88.3% domestic and 11.7% non-domestic). In May 2011, the average domestic tariff rate for the first 20 m^3 was about RM (Ringgit Malaysia) 0.50 /m^3 and for the first 35 m^3 about RM 0.73/m^3 (last tariff 2006). The average water tariff rate for the first 80 m^3 of industrial consumption was RM 1.60/m^3 (last tariff 2006).

The total length of pipes in 2009 and 2010, including different types, were approximately 10,659 and 10,792 km with 25.9% and 22.7% asbestos cement (AC) pipe, respectively. The domestic population served per km of pipe line was 224 and the domestic connection per km pipe line was 54; hence, the population served/domestic connection was 4.12 (MWIG, 2011). In 2011, the total length of pipes including different types was 10,972 km with 22.1% AC pipe. The domestic population served per km of pipe line was 221 and the domestic connection density was 54 connections per km pipe line; hence, the population served/domestic connection was 4.05 (MWIG, 2012).

In Malaysia, most states experience high NRW (Lee, 2005; Lee, 2007; Munisamy, 2009). According to MWIG (2012), the NRW percentage for Perak in 2011 was ranking No. 5 of the 14 states after Pulau Pinang (18.4%), Labuan (21.9%), Melaka (25.1%) and Johor (29.2%). International Water Association (IWA) and other international organizations recommend the use of the key indicators: NRW, physical losses, and commercial losses, all measured in L/connection/day; as for physical losses alone, IWA recommends the use of m^3/km of pipeline/day (McKenzie and Seago, 2005; Liemberger *et al.*, 2007; Wyatt, 2010; Kanakoudis and

Tsitsifli, 2010a). Consequently, the NRW for Perak in 2011 was 500 L/connection/day and 31 m^3/km of pipe/day (MWIG, 2012).

2.3.3.4 NRW in Malaysia and Perak

Table 2.1 summarises the available data on the percentages of NRW for Malaysia in general, and Perak in particular (ADB, 2001; Ku-Mahamud *et al.*, 2005; Lee, 2005; Lee, 2007; Ong *et al.*, 2007; Ku-Mahamud *et al.*, 2007a; Abidin, 2009; Adlan *et al.*, 2009; Toriman *et al.*, 2009; MWIG, 2011; MWIG, 2012). Beginning from the Sixth Malaysia Plan, NRW control has been a high priority issue by the Malaysian Government. For example, in the Seventh Malaysia Plan, the government spent more than RM500 million for the rehabilitation of water supply systems. In the Eighth Malaysia Plan, a total of RM640 million was allocated to reduce the NRW; the activities involved the replacement of old pipes and old water meters, reduction of water pilferages, and the rehabilitation and upgrading of WDSs. From Table 2.1, it is evident that NRW of Malaysia had decreased from 43% in 1987 to 36.7% in 2011 and for the state of Perak from 48.2% in 2001 to 30.4% in 2011.

Table 2.1: The average percentages of NRW in Malaysia and Perak

Year	**%NRW, Malaysia**	**Reference**	**% NRW, Perak**	**Reference**
1987	43%	Abidin (2009)		
1992			48.2%	ADB (2001)
1995	38%	Toriman *et al.* (2009)	42.6%	ADB (2001)
1998			42.4%	ADB (2001)
2000	28%	Toriman *et al.* (2009)	40.4%	ADB (2001)
2001	36.4%	Ku-Mahamud *et al.* (2005)	37.2%	Adlan *et al.* (2009)
2002	40.6%	Lee (2005)	30.2%	Lee (2005)
2003	40.6%	Lee (2007)	30.2%	Lee (2007)
2004			31.7%	Adlan *et al.* (2009)
2005			30.6%	Adlan *et al.* (2009)
2006			30.7%	Adlan *et al.* (2009)
2007	38%	Ku-Mahamud *et al.* (2007a)		
2008	37%	Abidin (2009)		
2009	36.6%	MWIG (2011)	30.7%	MWIG (2011)
2010	36.4%	MWIG (2011)	29.4%	MWIG (2011)
2011	36.7%	MWIG (2012)	30.4%	MWIG (2012)

2.4 The impact of water loss

2.4.1 The negative impact of high level of water loss

The quantity of water lost and the level of NRW are good indicators of the performance of a water utility system. High levels of NRW typically indicate a poorly managed water utility system (Frauendorfer *et al.*, 2010; Mutikanga *et al.*, 2012). Water losses in many countries around the world can be as high as 70% of the water input to the system (Babovic *et al.*, 2002; Palau *et al.*, 2012) meaning that significant amounts of water and revenue are being lost, forcing water utilities to develop effective water loss and NRW reduction strategies (Kanakoudis and Tsitsifli, 2010a; Boulos and AbouJaoude, 2011).

For example, in developing countries such as Brazil, the average rate of water losses has been registered, in 2007, equal to 39.1% which is similar to almost five billons m^3 of supplied water per year (Cheung *et al.*, 2010). In Turkey, the average water loss rate was found to be 51% in Turkish cities for the year 2003 and total water loss amount for all provincial centres was 1.5 billion m^3/year (Öztürk *et al.*, 2007). In an Iranian town, the level of NRW was about 1.00 million m^3 or 41% of total water supplied. The average pressure exceeded the 50 m maximum standard design value. In addition, more than 120 reported bursts were recorded during the study period of six months (Tabesh *et al.*, 2009). In Malaysia, the NRW percentage shows a drop from 36.6% in the year 2009 to 36.4% in the year 2010 (MWIG, 2011). However, the total volume of treated water loss was recorded an increase from 1.8 billion m^3 in 2009 to 1.87 billion m^3 in 2010 or equivalent to 3.5% increase. Hence, the estimated loss of revenue due to NRW in 2010 was RM 1.74 billion (AWER, 2012). Using acoustic leakage monitoring and to minimise water loss, after 12 months the Las Vegas District Water District identified 540 points of leaks on fire hydrants, water meters, valves and pipeline networks for a total savings of about 93.312 million gal per month. The cost of the water loss is about US $2.25 million with treatment and transporting cost (Morgan, 2006). More recently, the US Environmental Protection Agency estimates that water utilities in the United States will need to spend at least US $6 billion per year over the next 20 years to rehabilitate failing water distribution pipes (Boulos and AbouJaoude, 2011).

Today, water – energy nexus is one of the very hot issues, because the rise of the price of the fossil fuels and the environmental concerns as well (Pardo *et al.*, 2012). The energy consumption is the second most important expense in the water utilities after the staff costs (Muñoz-Trochez *et al.*, 2010). For example, the water-related energy consumption in California, USA consumes 19 % of the state's electricity and 32 % of the state's natural gas due to transportation of water for great distance (AWWA, 2009). In Malaysia, the energy costs in 2010 and 2011 were about 29% of the total operating expenditure (MWIG, 2012). Worldwide, the amount of energy consumed in water supply is roughly equivalent to the amount of energy used by Japan and Taiwan together, about 7% of the total energy consumption (Muñoz-Trochez *et al.*, 2010). When worldwide water loss average is estimated to be 30%, the same portion of energy is lost and leakage levels are responsible for more than 25% of total energy used (Feldman, 2009; Kanakoudis *et al.*, 2011a; Kanakoudis *et al.*, 2012).

Also, pipe burst could lead to large direct and indirect economic, social and environmental costs, such as water and energy loss, repair costs, traffic delays and factory production loss caused by inadequate water or service interruptions (Berardi *et al.*, 2008; Puust *et al.*, 2010; Xu *et al.*, 2011; Nazif *et al.*, 2013). Another important aspect of leaks is their influence on water quality by allowing intrusion of polluted groundwater (Clark and Goodrich, 1989; Colombo and Karney, 2002; Boulos and AbouJaoude, 2011; Mutikanga and Sharma, 2012; Mutikanga *et al.*, 2012). Intrusion of contaminants through water mains may occur during maintenance and repair events and through broken pipes (Sadiq *et al.*, 2008).

2.4.2 Benefits of reducing water loss

Financial, environmental, and social benefits may be acquired by improving management of WDSs, especially in reducing leakage (water loss) which results in reducing NRW (Hoye, 1980; McIntosh, 2003; Uyak *et al.*, 2007; Frauendorfer *et al.*, 2010; Wyatt, 2010; Kanakoudis *et al.*, 2011b; Yang *et al.*, 2013). In the developing world, about 16.1 billion m^3 are lost every year through water leakage in the distribution networks, sufficient to serve nearly 200 million people. If NRW levels are reduced by 50% only in the developing countries this would mean that every year more than 8 billion m^3 of treated water would be accessible to people suffering from water shortages and potentially, an additional 90 million people would access to fresh water resources (Kanakoudis and Tsitsifli, 2012). As a result, this reduction could generate an estimated additional US $2.9 billion in cash every year for the water sector (from both increased revenues and reduced costs) and save an estimated US$1.6 billion per year in production and pumping costs for public utilities (Kingdom *et al.*, 2006).

The benefits of reducing water loss can include: (i) need for less water to be produced, treated, and pumped, which translates into cost savings on operation and maintenance because of savings in energy and treatment costs; (ii) reduction in real losses, which results in more water being billed and revenue for utilities; (iii) sufficient understanding of consumption patterns, which allows utilities to optimise distribution systems; (iv) better knowledge of real consumption, which improves demand predictions; and (v) decreased sewage flows and pollution; undetected leaks can sometimes be quite large and can run directly into a sewer or a drain (McIntosh, 2003; Hunaidi *et al.*, 2004; Öztürk *et al.*, 2007; Frauendorfer *et al.*, 2010).

For instance, a study was conducted to assess water and energy savings in networks divided into pressure management areas (PMAs). It is known that WDS are very high energy consuming, and leaks results in an important amount of energy losses. Due to the installation of a pressure reducing valve (PRV) in a PMA, water savings was quantified as 0.15 cubic hectometers per year (Hm^3/year) and energy savings was 28.29 MWh/year, and economic savings in one year was € 35079 (Pardo *et al.*, 2012).