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EFFECTS OF NUMBER OF CONNECTIONS AND PIPE LENGTH TO THE WATER LOSSES IN MELAKA

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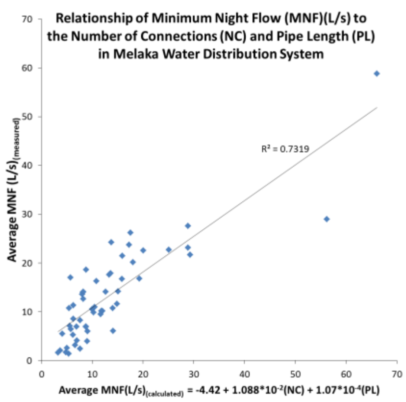
Graphical abstract



Abstract

One of the major challenges facing our water utilities is the high level of Non-Revenue Water (NRW) in the distribution networks. This paper assessed the performance of current management practices by Syarikat Air Melaka Berhad (SAMB) to deal with NRW. Information and NRW management data (from 2012 to 2013) were gathered and analysed. Statistical methods were used to evaluate the effects of pipe length and number of connections of the distribution network to the leakage level; and to determine the causes of leakage (water loss). In 2014, Melaka's NRW percentage was 21.4% as compared to the national average of 35.6%, which is the second lowest rate among the states in Malaysia. Results of the study revealed significant positive relationships between average MNF (L/s) with number of connections and pipe length, with the prediction model of average MNF (L/s)=-4.42+1.088*10^{-2}(NC)+1.07*10^{-4}(PL), R^2= 73.19%. The results also indicated that in a compact and urbanized city like Melaka, number of connections in the network appears to be most influential to the average MNF (water loss) (shown by a strong positive relationship, r = 0.847) as compared to the less compact zone (such as Perak) where pipe length appears to be more influential.

Keywords: Minimum night flow (MNF), number of connections (NC), Non-Revenue Water (NRW), pipe length (PL), water loss reduction

Abstrak

Cabaran yang dihadapi oleh pihak utiliti air adalah tingginya kadar air tidak berhasil (NRW). Kajian ini meneliti keberkesanan Syarikat Air Melaka Berhad (SAMB) untuk mengatasi NRW. Maklumat dan data (2012 sehingga 2013) dikumpul dan dianalisa. Kaedah statistik digunakan untuk mengkaji kesan jumlah penyambungan dan panjang paip bagi sistem agihan kepada kadar kehilangan air, bagi mengenalpasti punca kebocoran (kehilangan air). Pada 2014, kadar NRW di Melaka adalah 21.4% dibandingkan dengan peratusan purata Negara sebanyak 35.6%, menjadikan kadar itu sebagai kedua terendah di Malaysia. Dapatan menunjukkan jumlah penyambungan dan panjang paip akan meningkatkan kadar MNF=-4.42+1.088*10^{-2}(NC)+1.07*10^{-4}(PL), dan kadar R^2 = 73.19%. Hasil analisis juga menunjukkan bahawa untuk lokasi yang padat serta membangun seperti Melaka, jumlah penyambungan di dalam sistem agihan lebih mempengaruhi kadar MNF (r = 0.847) berbanding bagi lokasi yang kurang kompak (Perak) di mana panjang paip lebih mempengaruhi.

Kata kunci: Kehilangan air tidak berhasil (NRW), pengurangan kadar kebocoran, MNF, jumlah penyambungan, panjang paip

1.0 INTRODUCTION

Water loss and Non-revenue Water (NRW) within a utility's network are an enormous source of wastage. They add greatly to operating costs and present a major barrier to improve or extend the services especially to the unserved and new development areas [1]. Table 1 shows the annual estimated loss of revenue in Malaysia due to NRW between 2008 and 2013. Between 2008 and 2013, the total loss of revenue due to NRW is a staggering RM10.808 billion. The estimated financial loss due to NRW is more than 1/3 of revenue collected by water services industry annually. If full cost recovery is implemented in water services sector, the loss of revenue due to NRW is also set to increase in tandem with the increase in water tariff. Therefore, the people and businesses are force to pay for the inefficiency cost due to NRW [2].

Table 1 Annual Estimated Loss of Revenue due to NRW in Malaysia

Year	2008	2009	2010	2011	2012	2013
Annual Estimated Loss of Revenue RM (Billion)	1.624	1.632	1.786	1.848	1.915	2.003

Source: Association of Water and Energy Research Malaysia (AWER), 2014 [2]

In general, levels of NRW in Southeast Asia are amongst the highest in the world (when measured in appropriate performance indicators) [3]. In Malaysia, many of its major cities have experienced water supply problems in recent years due to droughts brought by climate change and human mismanagement [4]. At the same time, water issues such as water pollution, destruction of water catchment, water wastage, high nonrevenue water, low tariffs, and lack of public awareness for water conservation has seriously caused the depletion of water resources in the country [5]. The water sector will have to improve the way it uses its available water resources significantly in order to deal with the challenges ahead [1].

There are few success stories that demonstrate of which can be reduced in a sustainable manner. Malaysia is one of the pioneers of outsourcing the NRW management. Various private sector (NRW management contractors) are engaged under different contractual arrangements (some of them least partly performance based) [3]. In 2008, Melaka city, through Syarikat Air Melaka Berhad (SAMB) embarked on an aggressive plan to upgrade their water infrastructure in order to reduce the NRW loss. Leakage rates were at 33.9%, accounting 152000 cubic meters of water loss per day (which about 55.6 million cubic meters per year).

The factors which affect leakage levels are wide-ranging and are subject to regional variation; therefore, the new mandatory leakage targets are set for each individual company. However, cross-comparisons are uncertain and should be reviewed, and a more equitable basis for comparison must be found [6]. Water losses vary from system to system, and may be influenced by network length, number of connections, pressure fluctuation over the day, pipe material, soil characteristics, construction quality, level of internal and external pipe protection, kind of maintenance and upkeep of the network, leaks, burst, and age of the system [7]. Some of the most important drivers or factors are beyond the control of the utility, such as population density per kilometer of network, the type of distribution network, and the length of the network [6, 7]. The international experience shows that the greatest proportion of losses occurs in service connections rather than in mains, except in network characterized by a low density of connections [8]. The number of service connections per unit length of main may vary widely and leakage from ferrules and along service pipe may be significant.

Thus, this paper provides a review of the methods and tools applied to water loss management in Melaka water distribution system (WDS) and the performance of the water loss reduction strategies being implemented. Furthermore, this paper aims to evaluate the effects of network characteristics (physical characteristics such as pipe length and number of connection) to the leakage level in Melaka WDS. Majority of previous studies attempted to determine the contributions of major factor affecting water loss to a water supply network (such as pressure, age and type of the network), but this study will only focus on the effects of physical characteristics of the water systems.

1.1 Literature Review

1.1.1 Non-revenue Water (NRW)

Malaysia as well as many other countries commonly used percentage of Non-revenue Water (NRW) as a terminology to measure the water losses. NRW is the volume of water supplied into the water distribution system that does not bring income or revenue to the water supply authorities concerned [9]. NRW can also be defined as 'the difference between System Input Volume and Billed Authorized Consumption' according to the International Water Association (IWA) Task Force on Water Loss. System input is 'the annual input to a defined part of the water supply system' and billed authorized consumption, according to the task force is 'billed metered consumption including water exported and billed unmetered consumption'. NRW is comprised of three components [1]:

- Physical losses include leakage from all parts of the distribution system and overflows at the utility's storage tanks. They can be caused by poor operations and maintenance, the lack of active leakage control, and poor quality of underground assets;

- Commercial losses include customer meter under-registration, data-handling errors, and theft of water in various forms;
- Unbilled authorized consumption includes water used by the utility for operational purposes, water used for firefighting, and water provided free to certain consumer groups.

A high NRW level indicates a poorly run water utility that lacks of governance, autonomy, accountability and the technical and managerial skills necessary to provide reliable service. Not understanding the magnitude, sources and cost of NRW is one of the main reasons for insufficient NRW reduction efforts around the world [3].

The first stage of assessing NRW is to make a water balance within the system in order to know how much water is actually used and paid for but also how much water is lost and how it is lost. The International Water Association (IWA) has developed a standard water balance structure and terminology that has been adopted by national associations in many countries across the world [10]. Figure 1 gives an overview of the components of a water balance.

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Commercial Losses	Unauthorized Consumption	
			Customer Meter Inaccuracies and Data handling Errors	
		Physical Losses	Leakage and Overflows from the Utilities Storage Tanks	
			Leakage on Transmission and Distribution Mains	
			Leakage on Service Connections up to the Customer Meter	

Figure 1 Water balance showing NRW components [10]

1.1.2 District Metering Areas (DMAs)

District metering is a key weapon in the war against leaks. A district is a defined area of the distribution system that can be isolated by boundary valves and for which the quantities of water entering and leaving can be metered. The subsequent analysis of flow and pressure, especially at night when a high proportion of users are inactive, it enables leakage specialists to calculate the level of leaks in the district. This can be used not only to determine whether work should be undertaken to reduce leakage, but also to compare levels of leakage in different districts and thereby to target maintenance teams into those areas where they will have the greatest impact.

The role of DMAs is to divide the network into manageable sections that make it easier to determine where bursts are and then to repair them. The DMA's enabled the utility to measure the overall flow in and out of a zone and with the help of calibrated meters, the team could then determine the most challenged zones that needed serious attention with infrastructure replacements. Besides, DMA also enables management and control of pressure in each zone to supply exactly the right amount of pressure the customers have in each required DMA. It is also a typical demand to fluctuate between night and day, causing pressure to fluctuate, which the pressure reducing valve (PRV) needs to accommodate for.

1.1.3 Leakage and Factors Affecting Leaks

The most obvious indication of the physical deterioration and failure of the pipe network is leakage. Pipe failures can be regarded as either persistent, progressive or sudden [11]. Leaks waste both money and a precious natural source, and they create a public health risk. The primary economic loss is the cost of raw water, its treatment, and its transportation. Leakage leads to additional economic loss in the form of damage to the pipe network itself. Risk to public health can be caused by contaminants entering the pipe through leak openings if water pressure in the distribution system is lost [12].

Leakage occurs in different components of the distribution system: transmission pipes, distribution pipes, joints, valves, and fire hydrants. Old or poorly constructed pipelines, inadequate corrosion protection, poorly maintained valves, material defects, faulty installation, excessive water pressure, water hammer, ground movement due to drought or freezing, excessive loads and vibration from road traffic are some of the factors contributing to leakage [12, 13]. Examples of the former include leakage from fractured pipe joints (such as might occur as a result of differential ground movement) or leakage from pinhole leaks in corroded pipe works (such as might occur from iron placed in aggressive ground conditions). In such cases, the rate of leakage can remain relatively consistent and locally small. Although with a number of such minor leaks over an area, the total leakage over an area can be quite significant [1].

1.2 The Study Area

The study focused on the water supply system of Melaka, Malaysia with particular reference to management strategies adopted for efficient water service delivery in Melaka and its environs with emphasis on management of non-revenue water. Syarikat Air Melaka Berhad (SAMB) is responsible for providing water services to three main districts in Melaka, which are Alor Gajah District, Jasin District and Melaka Tengah District. According to National Water Services Commission (2015), a total of 100% of Melaka's population has accessed to water supply. The total number of connections was 274,758 in 2014 (86.9% domestic and 13.1% non-domestic). As per March 2013, the total length of different pipes was approximately 2846 km. The NRW percentage for Melaka 2013 and 2014 were 22.1% and 21.4% respectively, with the reserve margin of the Water Treatment Plant of 4.7% and 15.6% both in the year 2013 and 2014.

2.0 METHODOLOGY

2.1 NRW Management in Melaka Water Distribution System

The first step of this study was to assess the current NRW level and management strategies in Melaka water utility system (SAMB). Related data and reports were collected from the relative units and departments in SAMB; extensive review of relevant data and reports has been conducted, and interviews throughout several departments in the utility headquarter have been carried out. Non revenue data (basically involving water losses throughout the water supply system) were collected from the relevant unit. The monthly record of leakages and repaired leakages, burst monitoring and maintenance, reservoir monitoring and other procedures and strategies being implemented by SAMB are reviewed and analyzed. On the other hand, alternatives and strategies to manage and overcome water losses at the study area were analyzed to evaluate the efficiency of the current NRW management. Literature review on NRW and NRW strategies have been reviewed. This literature review includes journal articles on NRW management study cases and governments report.

The scope for this study includes review of existing data and information of these study areas. Data used for this study is a one-year data from January 2012 to March 2013. The data were analyzed within the study area to assess the leakage volume (water losses) within water distribution system of Melaka water utility. The data shows effects of network characteristics (physical characteristics) to the leakage levels and minimum night flows (MNF) are evaluated.

The performance of existing strategies employed for combating NRW in Melaka is measured by comparing the NRW level in Melaka to the National level of NRW and NRW in Penang States (as Penang has the lowest rate of NRW among all the states in Malaysia). The literature review on NRW and NRW strategies have also been reviewed [2, 4, 5, 20].

2.2 Minimum Night Flow (MNF), Legitimate Night Flow (LNF) and Net Night Flow (NNF)

NRW management begins with measurements and determination of actual figure of water losses within a system. This can be done using the top-down approach, bottom-up approach or component-based analysis. In this study, the method used to evaluate the NRW level in Melaka is bottom-up approach.

Bottom-up approach uses Minimum Night Flow (MNF) analysis. MNF analysis allows relatively strict criteria to be established for calculating the factors related to losses, since most of the population is not 'active' during the night and that is when consumption can be more easily measured or estimated [21].

MNF analysis is the lowest flow into the District Metered Area (DMA) over a 24-hour period, which generally occurs at night when most consumers are inactive. Besides, Minimum Night Flow analysis entails identifying in advance the potential large nightly water consumers (also known as Big Night Consumer, BNC) within the DMA. Accordingly, estimating the leakage in the MNF period is carried out by subtracting legitimate night uses (LNF) and Big Night Consumer (BNC) from the Minimum Night Flow (MNF). Water is used legitimately but is not metered including mains flushing, fire fighting and supply to un-metered premises, illegal connections and system leakage.

Legitimate Night Flow (LNF) is the estimated volume of water consumption in the early morning. Total water flow can be obtained from the meter reading at the customer's premises. Typically, meter readings from 10% of premises in a particular zone or area are taken to obtain the average hourly flow. The result of this calculation can be used to calculate the Net Night Flow (NNF).

Net Night Flow (NNF) is the volume of water lost through leakage. NNF is obtained by subtracting the legitimate night flow (LNF) from the Minimum Night Flow (MNF). It represents the volume of water lost within the chosen zone. It is derived as in Equation (1):

$$\mathrm{NNF} = \mathrm{MNF} - \mathrm{LNF} \quad (1)$$

The level of Net Night Flow (NNF) or the portion of night flow directly attribute to leakage are obtained by subtracting the LNF from the recorded MNF.

Leakage is proportional to the pressure in the system. Similar to water flows into the DMA, the DMA average pressure will change over a 24-hour period. Pressure is directly proportional to flow due to frictional headlosses within the system, and thus when the DMA has its lowest inflows, the pressure will be at its highest. This is because frictional headloss is proportional to velocity, so when flows are low, the velocities in the pipes are also low and it brings less headloss. Therefore, the NNF or leakage calculated for the minimum night flow will not be a true representation of leakage across a 24-hour period.

To obtain a true average 24-hour leakage value when applied to the NNF, the water utility must also determine a pressure factor, or T factor. The T factor is calculated by using a data logger to record pressure over a 24-hour period, and then using those measurements to calculate the average of 24-hour pressure. This average 24-hour pressure is compared to the system pressure during the minimum night period and a factor applied [14].

Representing SAMB, Ranhill Water Services (RWS) has introduced the calculation of T factor for Melaka water distribution system to gain the precise magnitude of leakage. T factor (Equation (2)) is calculated by adding the total leakage index, divided by the highest leakage index, and then multiplied by two-hour interval reading. Pressure data loggers are installed at each point to identify the highest and lowest point of pressure from the 24-hours pressure data.

$$T = (\text{Total Leakage Index} / \text{Highest Leakage Index}) * 2 \text{ hours} \quad (2)$$

2.3 Five Forces of Water Loss Reduction Strategies in Melaka Water Distribution System

Syarikat Air Melaka Berhad (SAMB) has awarded Ranhill Water Services (RWS) a contract for Consultancy Services for NRW reduction in the State of Melaka within two years. The objectives of this contract are to consult and assist SAMB in undertaking the NRW reduction and maintaining programmed to ensure the sustainability of current NRW level. As for this objective, SAMB and RWS are working together on the following water loss reduction activities (Figure 2).

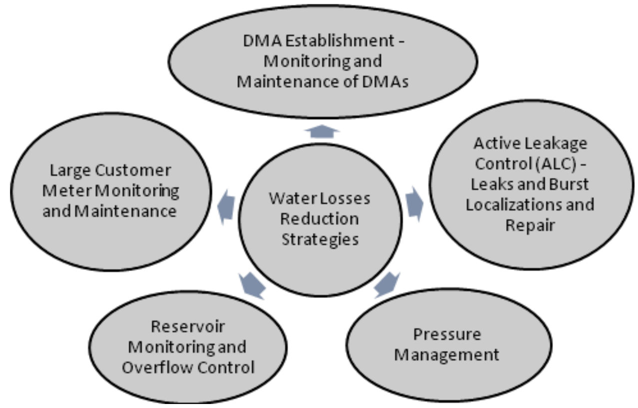


Figure 2 Five Forces Water Loss Control methodology by SAMB and RWS

2.3.1 District Metered Areas (DMAs) Establishment (Monitoring and Maintenance)

The leakage reduction program has been implemented by SAMB in more than 91.90% of the total length of the network, of which the distribution systems are divided into about 171 DMAs (approximately). To determine the compliance of NRW, all 171 DMAs are selected where these DMAs are divided according to main districts, namely Melaka Tengah (MT01 – MT104), Alor Gajah (AG01 – AG40) and Jasin (JA01 – JA27). A sensitive flow measurement device is permanently installed onto the inlet pipes to each DMA and flow and pressure profiles are recorded using data loggers.

For each DMA, Minimum Night Flow (MNF) profiles are analyzed, in conjunction with pressure profiles recorded by other pressure loggers (Advanced Pressure Management) strategically placed inside the DMA, to identify where an intervention with active leakage control is economically justified. This method allows SAMB engineers to prioritize high leakage areas.

In SAMB, DMA Monitoring and Maintenance team will systematically monitor all the DMA periodically or by web-based monitoring system. The monitoring of individuals DMAs is important in the sense that it will alert SAMB and RWS immediately is a problem occur and potentially reduce the subsequent time to locate and repair. This continuous monitoring and alert system will ultimately reduce the volume of water lost in the water supply system. Even though the aims of both SAMB and RWS is to achieve 100% readable DMAs, there are few problems contribute to unreadable meter such as meter problems, necessary relocation of meter, transmitter and battery problem.

2.3.2 Active Leakage Control (ALC), Leak Localizing and Repaired, and Burst Monitoring

Active leakage control (ALC) tries to reduce the time that detectable but unreported leaks are active by locating and repairing them, being considered as an effective method of leakage management [13]. The main method of ALC being practiced is leakage monitoring. SAMB conducted flow monitoring into zones (by District Metered Areas (DMA)) to quantify leakage and priorities leak detection activities. To enable efficient control of recoverable losses, DMAs are being used both to identify and reduce recoverable leakage in short term and then to monitor and control leakage in an ongoing manner.

After high leakage areas are identified and leakage volume is quantified, leak localisation was undertaken using Step Testing and leaks were found by using Visual and Sounding methods (VIS). Leak detection may however be quite difficult for a number of reasons, for example, clay soils below the surface become water logged, delaying identification of leaks; the uneven road surface containing numerous potholes that are backfilled with materials of unequal density makes acoustic leak localisation difficult [15].

A total of 2985 leaks were detected within all DMAs and 2303 (60.22%) leaks were then proceed for repair works. The percentage of leaks detected and repaired is shown in Figure 3. The reported minor leaks included 91% (2728 reported leaks) of the overall detected leaks within the DMAs. In this case, with a number of such minor leaks over an area, the total leakage can be quite significant. Most of the minor leak cases are due to leakage at the communication pipes, sockets, meter stands, stop cocks, and at ferrule connections. Nevertheless, the leaks occurrence in communication pipes contributed the most significant cases among the others with 1700 detected cases and included about 78.6% from the overall minor detected leaks. Communication pipes were classified into two categories which are High Density Polyethylene (HDPE) pipes and Galvanized Iron (GI) pipe and HDPE pipe itself contributed 88% from the overall leaks of communication pipes. As compared to GI pipes, HDPE pipes are subject to stress cracking and are also poor in weathering resistance. Leakages in distribution networks with plastic pipes are common, in most case, it is because of the weak or improper connection.

Burst can be identified as event with flow rates greater than those of background losses and therefore detectable by standard leak detection techniques. Reported burst are visible leaks that are brought to the attention of the water utility by the general public or the water supply organization's own operatives. The objective of the burst monitoring activities is to identify the highest number of burst and action taken to overcome it as well as to reduce the number of total occurrence of burst. From May 2012 until February 2013, a total of burst has been reported was 147 cases.

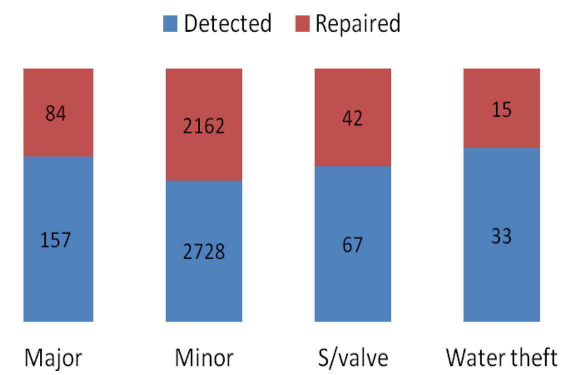


Figure 3 Number of leaks detected and repaired

2.3.3 Pressure Management

Advanced Pressure Management (APM) refers to monitoring and managing pressure with advanced equipment. The activities will include pressure monitoring (minimum and maximum pressure), and identification of critical pressure point in DMA. This will lead to the recommendation of several suitable locations to install advanced pressure monitoring equipment and servicing PRV. A total of 123 Pressure Reducing Valve (PRV) in size from 100mm and 200mm (Figure 4) are installed in all the three districts as per March 2013, to provide a consistent flow in each DMA as required by their users. Table 2 illustrated the number of DMA establishment and PRV installed within the districts in Melaka.

Figure 4 PRV installed with advanced pressure monitoring

Table 2 DMA establishment for each district

Districts	Total DMA	Coverage Percentage (%)	Pressure Reducing Valve (PRV)
Melaka Tengah	104	90.90	73
Alor Gajah	40	91.87	38
Jasin	27	96.12	12
Total	171	91.90	123

2.3.4 Reservoir Monitoring and Overflow Control

Overflows from reservoir are one of the major contributors of NRW, however, they can easily be quantified and reduced. SAMB and RWS continually monitored reservoir levels, observed the overflows and then estimated the average duration and flow rate of the events. Causes of the overflows are also identified which enable the corrective action to be done effectively. Melaka's older style level valves had become inaccurate and allowed reservoirs to overflow, wasting water and increasing NRW. To fix this issue, they were replaced with altitude valves that are used to control maximum levels of the reservoirs and the drawdown of the reservoirs accurately before re-filling. This new level control technology with altitude pilots, now accurately controls the levels repeatedly and dependably [16].

2.3.5 Large Customer Meter Replacement and Maintenance

Customers consuming large volume of water should be ranked as 'Top Customers'. SAMB determined 100 top meter consumers to be monitored closely. Proper selection and maintenance of this large customer meters is essential due to its large potential impact on SAMB revenue.

A large customer meter is defined as any meter with a line size of 38mm (1.5") or greater, typically industrial, commercial and institutional users.[14]

2.4 Network Characteristics in Melaka Water Distribution System

Besides pressure of the system, age of system (pipe age) and types of mains, and other factors such as climate, type of ground and traffic loading, length of the pipe network and also number of connection are also the most dominant factor that contributes to leakage. In this study, influence of network length (pipe length, PL), and number of connections (NC) to the leakage level in Melaka WDS were evaluated. Figure 5 shows the length of pipe for all the DMAs in the system. Most of the DMAs have pipe lengths ranging below 30 kilometer. The number of connections in the system is expressed in terms of its connection density. Connection density is the number of connection divided by pipe length (connection per unit length). From Figure 6 below, it is observed that some of the connection densities in the system are quite dense (39% DMAs has more than 100 connections per kilometer of pipe network).

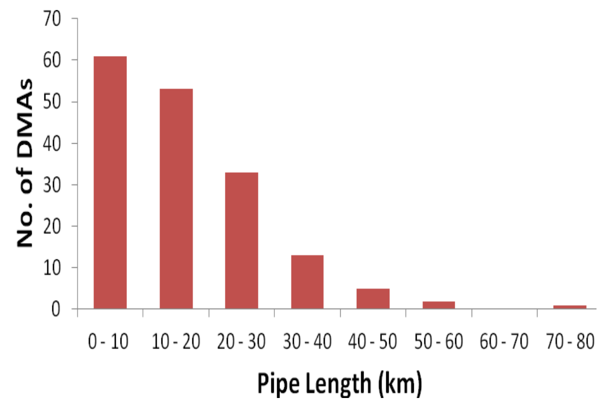


Figure 5 Length of pipe

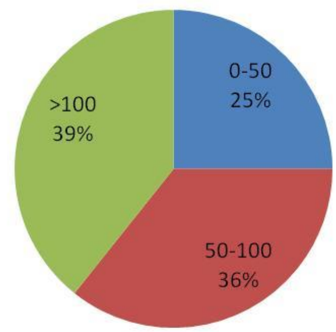


Figure 6 Connection densities for overall DMAs

Out of 168 DMAs, 55 DMAs were randomly selected. In order to determine the effects of network characteristics (mainly pipe length, and number of connections), correlation and Regression Analysis (using Minitab version 17) were used as a statistical technique to determine the factors that contributed to the minimum night flow (MNF) and leakage levels in the WDS. The results obtained are then compared to previous studies as to observe the most influence factor of water loss in Melaka WDS and its causes.

Furthermore, considerations on other driving factors to water loss were also analyzed. Factors including land area, population, population density, connection density, and some other factors are taken into consideration to classify the state of Melaka and other states then to relate it with the impacts to water losses.

3.0 RESULTS AND DISCUSSION

3.1 Performance of Water Loss Reduction Strategies

Although assessing the correct value for NRW in any system is often difficult, a good quality data is needed to be interpreted accurately for control purposes and a clear understanding of supply boundaries is therefore most significant. Currently, there are two main methods for estimating leakage in system. They are the total integrated flow method and the total night flow method. Both of these methods involve subtracting the measured output (i.e. water consumption) from the measured input (i.e. water production). The remaining unaccounted for water is non-revenue water, the majority of which is related to system leakage.

Beginning May 2012, SAMB has implemented a number of water conservation strategies to improve the City's potable water supply and precious water resources (as elaborated in section 3.0). In this study, performances of current NRW management methods are analyzed into three aspects:

1. Net Night Flow and Minimum Night Flow reductions
2. Leakage reduction
3. Percentage of NRW reduction in Melaka WDS and in comparison with national levels and other states.

3.1.1 Net Night Flow (NNF) and Minimum Night Flow (MNF) Reductions

Reduction activities conducted from May 2012 until March 2013 had shown a significant reduction of Net Night Flow (NNF) (methods of calculations as per mentioned in Methodology). Using NNF and MNF values of April 2012 which is 1187.76 L/s and 2106.29 L/s as baseline data, the flows was reduced gradually to 966.54 L/s (NNF) and 1983.87 L/s (MNF) in March 2013. Therefore, the total reduction for NNF was 221.22 L/s and 122.42 L/s reduction was measured for MNF. Figure 7 shows the progress reductions of NNF and MNF as compared to the baseline data (April 2012 – before the commencement of reduction strategies), and the percentage of NNF and MNF reduction.

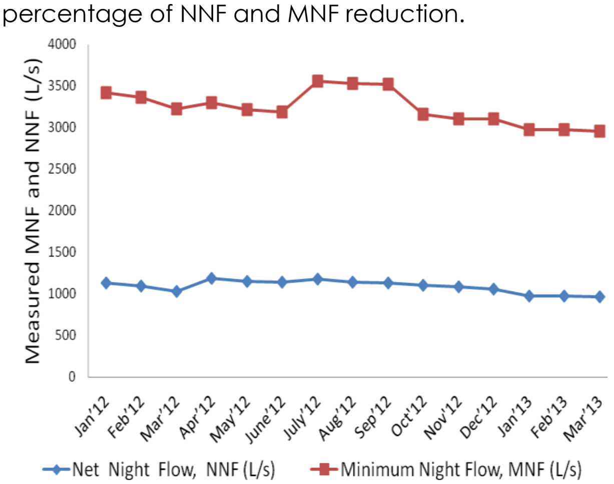


Figure 7 Progress of measured Net Night Flow (NNF) and Minumum Night Flow

3.1.2 Leakage Reduction for Melaka Water Distribution System

Reducing water losses helps in stretching existing supplies to meet increased needs. This could help defer the construction of new water facilities, such as new source, reservoir or treatment plants. Repairing the leak will also save money for the utility, including reduced power costs to deliver water and reduced chemical costs to treat water.

Data from Step Testing conducted by RWS from January 2012 until March 2013 shows a significant reduction in leakage for Melaka Water Distribution System. Figure 8 shows the total volume and percentage of leakage from total flow into the DMAs from January 2012 until March 2013 for Melaka state. Data obtained are from Step Testing conducted by SAMB. It can be observed that leakage percentage fluctuated but decreased gradually from October 2012 to March 2013 measurements with the minimum percentage observed in December 2012 with only 19.14 percent of leakage from 418126.45 m^3 per day of water supplied to the consumer. Figure 9 below shows the percentage of leakage before and after the commencement of Active Leakage Control program. Performance of leakage reduction strategies is proven with the percentage of leakage before and after commencement of leakage reduction strategies is observed as 4.28% (from 25.76% in January 2012 to 21.48% in March 2013).

Generally, almost 80% of the leakage contributed to Non-revenue Water (NRW) and the rest is due to apparent loss. By using Step Test Method, leakage percentage (21.48%) is assumed as NRW level as per March 2013 for Melaka States. The Non-Revenue Water percentage is a simplified comparison of the quantity of water produced and the quantity of water generating revenue (as shown in Table 3). An apparent decrease in NRW percentage from 32.85% to 22.51% is observed beginning in the year 2008, showing a significant reduction of 10.34%.

Figure 8 Total volume and percentage of leakage versus total flow

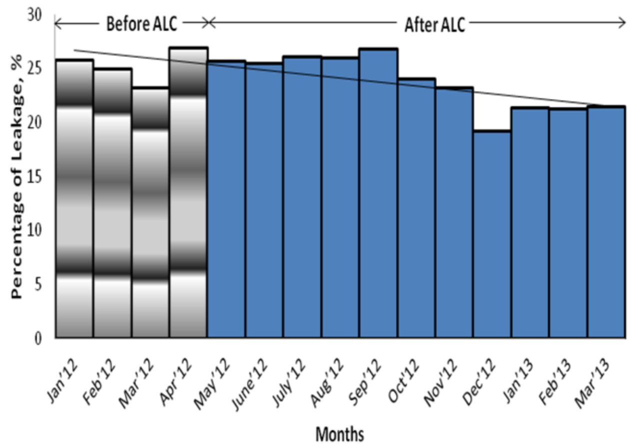


Figure 9 Percentage of leakage before and after Active Leakage Control (ALC) program

Table 3 Percentage of Melaka non-revenue water

	2008	2009	2010	2011	February 2013
Production ($x10^6$ m^3)	162.15	161.55	161.29	166.04	14.65
Billing Consumed ($x10^6$ m^3)	108.88	114.04	119.54	124.43	11.36
NRW ($x10^6$ m^3)	53.27	47.51	41.75	41.611	3.30
% of NRW	32.85	29.41	25.89	25.06	22.51
Leakage DMA (m^3/day)	69689	51520	40610		74265.57
Pipe Burst (nos)	3109	2919	2098		147 (May'12-Feb'13)

Additional Sources:

1. Malaysian Water Industry Guide 2007 in Non-Revenue Water Audit Guidelines, by National Audit Department Malaysia, 2014 [17].
2. Water Services Industry Performance Report, Suruhanjaya Perkhidmatan Air Negara, 2014 [18].

3.1.3 NRW Reduction for Melaka and Comparison with other States

The country's water security has be threatened by many water issues caused by river pollution, destruction of water catchment, water wastage, high water loss, low water tariff, poor water conservation practices, etc. Above all, high non-revenue water (NRW) rates have caused a large amount of treated water to be wastes via pipe leakage, pipe burst, meter inaccuracy, water theft, etc [19]. Malaysia's average NRW rate was 36.4%, 36.6% and 35.6% for the year 2012, 2013 and 2014 respectively. This value reflected that more than thirty percent of the treated water to be supply to the consumer was lost due to NRW.

The NRW for each state in Malaysia vary greatly and the percentage ranging from 18.3% to 55.8% in the year 2014. Only Johor, Kelantan, Melaka, Negeri Sembilan, Pahang, Perlis and Terengganu recorded drop on NRW percentage. Furthermore, the percentage of NRW for the states of Kedah, Kelantan, Pahang, Perlis and Sabah are higher than the national average of NRW (36.2%) (Figure 10), with Perlis recorded the highest NRW loss in percentage that are 66.4%, 62.4% and 55.8% in 2012, 2013 and 2014 respectively. Pulau Pinang and Melaka are among the states with the lowest NRW percentage while Perlis, the second smallest state in Malaysia has recorded the highest NRW percentage. The NRW percentage of Melaka states fluctuate and remain decreased for the past nine years (28.85 in 2005 to 21.4% in 2014), below the average national percentage of NRW, and almost reach to the same level with Penang with the target of below 20% of non-revenue water (Figure 11). Similar to the effort done by SAMB and RWS, Perbadanan Bekalan Air Pulau Pinang (PBAPP) also has proactive strategies in managing NRW effectively that should be followed by other states in ensuring an efficient and effective management of non-revenue water.

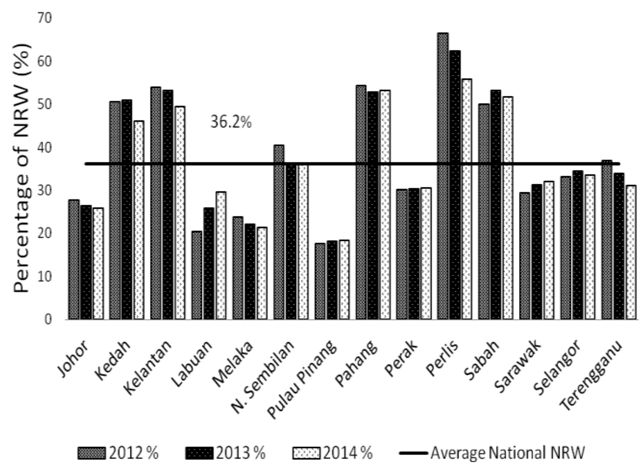


Figure 10 Percentage of non-revenue water for each states as compared to the average National NRW percentage

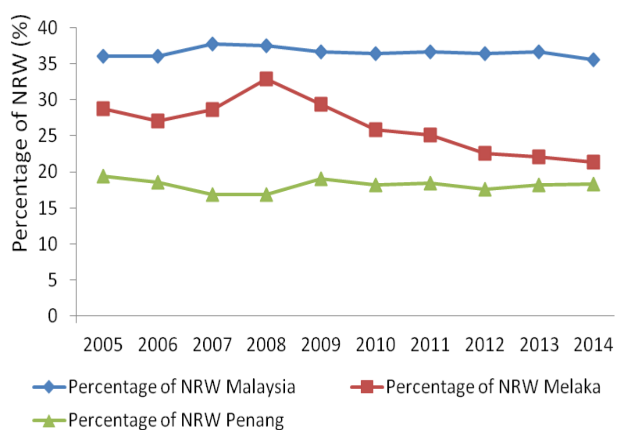


Figure 11 The comparison of percentage of NRW in Malaysia, Melaka and Penang from 2005 until 2014

Many strategies of NRW reduction are developed at different levels in both Melaka and Penang States. Table 4 shows the actions undertaken by SAMB (Melaka States) and PBAPP (Penang States) and the level of intervention of each strategy. The levels of intervention for each strategy were analyzed not only to identify the strength and opportunities that allow SAMB to enhance its level of intervention and this can help the utility to reach more advanced level; but also weaknesses and threats that prevent the utility to meet its target. In this case, Penang has the advantage of high water supply network density and high population density within a small area. Moreover, a high water supply network density with poor (low) water resources but high water demand have forced Penang to increase its efficiency in NRW management. Besides, the high population density of Penang state has made incidents like pipe burst and leakages easier to be discovered by the public [19].

NRW rate at the state of Penang in 1999 was 23.9% of the total water produced, and it was successfully reduced to 18.3% in 2014 among the lowest rate of NRW in Malaysia. If compared with the national average of 36.4%, PBAPP does show the achievements of good water governance in securing water resources in Penang State [20]. From 2006 to 2010, a total of 272 km of outdated pipe which prone to bursting was replaced to avoid the incidences of pipe burst or leakage. In addition, a total of 139489 of aging water meter that is older than 9 years old has been replaced to ensure the accuracy of the meter reading. Besides, PBAPP has formed a 24 hour call center to handle the issues related to water supply network reported by public, including issues of pipe burst or leaking. As for unreported cases, average response time and restoration time for pipe leaking are targeted within 2 hours and 3 days respectively. Up to 2009, there were total of 129 DMAs formed by PBAPP and with the DMAs in place, PBAPP reduced the rate of real loss to 13.1% from 14.2% in 2006 [20]. In terms of apparent loss, PBAPP has conducted several actions such as replacing aging meter older than 9 years, and disconnecting illegal pipe connection by about 95%. PBAPP also has implemented Geographical Information System (GIS), as a tool to control the event of pipe burst.

Table 4 Current level of intervention of the reduction strategies between SAMB and PBAPP

Strategies	SAMB Interventions	PBAPP Interventions
Illegal Use Reduction	Occasional detection of illegal connections	Thorough disconnections for illegal use
Meters Replacement	Only defective meters are changed	Meter older than 9 years are replaced
Active Leakage Detection and Control	Whole networks are surveyed and controlled	Significant preventative maintenance
DMAs with Pressure Management	Several DMAs and Pressure Management with regular monitoring	Several DMAs and Pressure Management with regular monitoring
Households Connections Replacement	Replacement when leakage reported or detected	Replacement when leakage reported or detected
Mains Replacement	Irregular replacement of old pipes	Main replacement policy in place
Fast Leaks and Burst Repair	Replacement when leakage reported	Repairing burst and leaks, with additional of GIS to control pipe leaks and burst

3.2 The Impacts of Physical Characteristics of the Water Systems on Water Losses

It would be difficult to directly identify and characterize the causes of the water losses in a water distribution system. A large number of mostly technical and environmental factors affect municipal leakage rate [6[. Besides placing a considerable emphasis on management factors, physical factors also very important [27]. Hence, due to limited data, the analysis of factors affecting water loss (leakage) in Melaka WDS in this study focuses on network characteristic (physical factors) such as pipe length (PL) and number of connections (NC) in each DMAs with the hypothesis as follows:

i. The pipe length should be positively related to water losses.
ii. The higher the number of connections in a distribution network, the higher the failure rates and large volume of losses.

3.2.1 Correlation and SLRs of Average MNF with Number of Connections and Pipe Length

From 168 DMAs, average of MNF (L/s) was observed from 15 months data for 55 DMAs (selected randomly). Statistical analysis were used to determine factors contributing to minimum night flow (MNF) (L/s) as MNF is a common method used to evaluate water loss in a network. A correlation test of average MNF (L/s), number of connections, and pipe length in each zone was performed. The result shows that the Pearson correlation coefficient (r) was 0.847 for the number of connections and 0.443 for the pipe length. As indicated in Table 5, the correlation test shows that since the P-values are low, there is sufficient evidence that linear relationships between the number of connections and pipe length with average MNF (L/s) exist. The present finding of the significant relationships of average MNF (L/s) to the number of connections and pipe length of the network is consistent with that obtained in previous investigation (Skipworth *et al.* [6], Alkasseh *et al*. [7], Cannarozo *et al.* [8], Gomes *et al.* [21], Mutinkanga *et al.* [23], and Warren [24]).

Table 5 Pearson Correlation: Average MNF (L/s), number of connections and pipe length

Independent variable	Average MNF (L/s)	
	r	p-value
No. of connections (NC)	0.847	0.000
Pipe length (PL) (meter)	0.443	0.001

A significant relationships of the average MNF (L/s) to the number of connections and pipe length of the network are shown in the regression equations from the Simple Linear Regression (SLR) as shown in Table 6. The values of R squared indicate that number of connections (R^2 = 0.717) in a DMA have more influence to the average MNF (L/s) compared to the pipe length (R^2 = 0.196).

Table 6 SLRs: Average MNF (L/s) versus number of connections and pipe length

Independent variables	Regression	R-square
No. of connections (NC)	MNF(L/s)= -3.147+1.159*10^{-2}(NC)	0.717
Pipe length (meter)(PL)	MNF(L/s)= 5.573+3.59*10^{-4} (PL)	0.196

3.2.2 MLR of Average MNF with Number of Connections and Pipe Length

Finally, the prediction model for average MNF (L/s) using Multiple Linear Regression (MLR) as in Table 7 was achieved. The output of the Stepwise Selection, Backward Elimination and Forward Selection shows the same independent variables, which is the number of connections and pipe length. The p-value for the regression model (0.000) shows that the model estimated by the regression procedure is significant at 5% significance level. The Variation Inflation Factors (VIFs) for both independent variables are close to 1, which indicates that the predictors are not correlated. VIFs are less than 10 thus show that the regression coefficient is not poorly estimated due to severe multicollinearity. The R^2 value indicates that the predictors explain 73.19% of the variance in Average MNF. The adjusted R^2 is 72.15%, which accounts for the number of predictors in the model. Both values indicate that the model fits the data well. The predicted R^2 value is 67.44% and is close to the R^2 and adjusted R^2. Thus, the model does not appear to be overfit and has adequate predictive ability. The F test value is 70.96 and it represents a strong relationship between the dependent variable (average MNF) and the independent variables (pipe length and number of connections). This shows that the regression model was statistically significant.

Table 7 MLR output

Dependent variable	Average MNF (L/s)
Independent variables	Number of connections (NC), pipe length (PL)(meter)
No. of Observation	55
R-square	73.19%
R-square (adj)	72.15%
R-square (pred)	67.44%
F test	70.96
p-value for F test	0.000
VIF for number of connections	1.18
VIF for pipe length	1.18

The residual plots for the data are shown in Figure 12(a-d). The normal probability plot (Figure 12(a)) shows an approximately linear pattern consistent with a normal distribution. The point at the upper-right corner of the plot may be outliers. The plot of residuals versus the fitted values (Figure 12(b)) shows a positive linear relationship exception of two outlier points. The histogram (Figure 12(c)) indicates that outlier exist in the data, shown by the bar on the far right side of the plot. The prediction model of average MNF (L/s) is given as in Equation (3):

$$\text{MNF (L/s)} = -4.42 + 1.088*10^{-2}\ (\text{NC}) + 1.07*10^{-4}\ (\text{PL}) \quad (3)$$

The variation of MNF (L/s) shows a positive relationship with number of connections and pipe length of the network, as explain in Figure 13. The coefficient shows that increase in number of connection (say about 100 numbers of new connections) is associated with an increase in average MNF of 1.088 (L/s). The length of the network (pipe length) is also positively related with water losses. The effect is significant with the increase of 10000 meter (10 kilometer) of pipe length leading to the increase in average MNF of 1.070 (L/s).

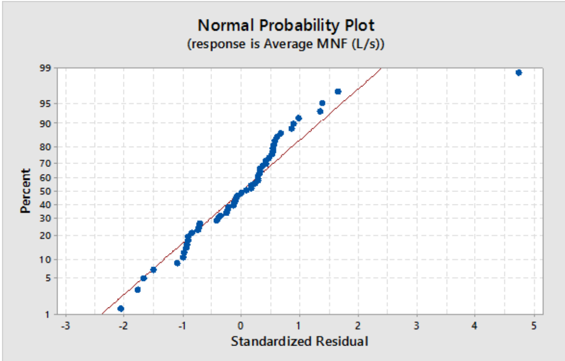


Figure 12(a) Normal probability plots of residuals for average MNF (L/s)

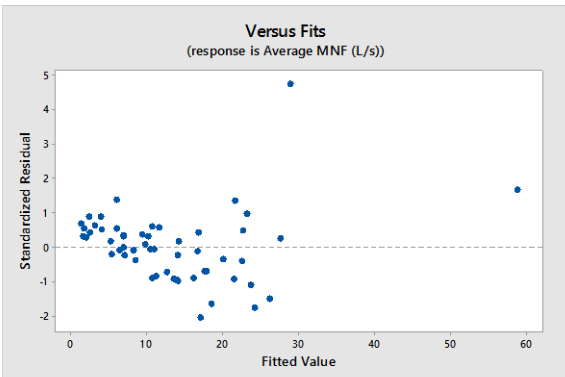


Figure 12(b) Residuals versus fits for average MNF (L/s)

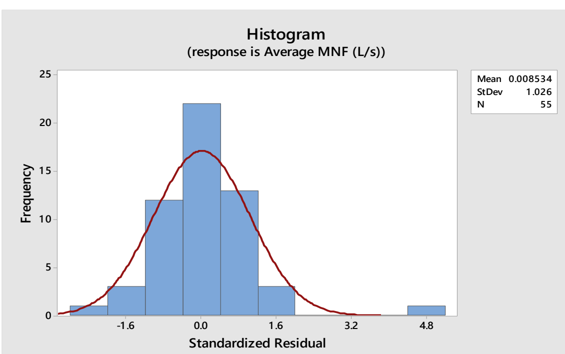


Figure 12(c) Residuals histogram for average MNF (L/s)

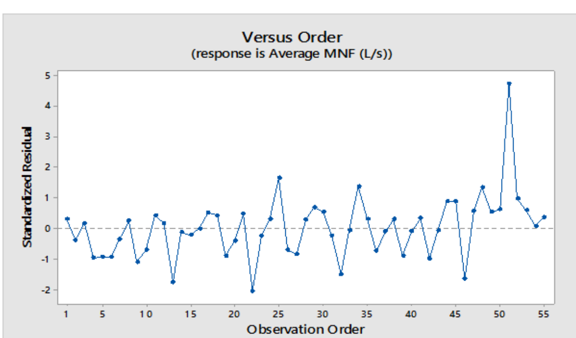


Figure 12(d) Residuals versus order for average MNF (L/s)

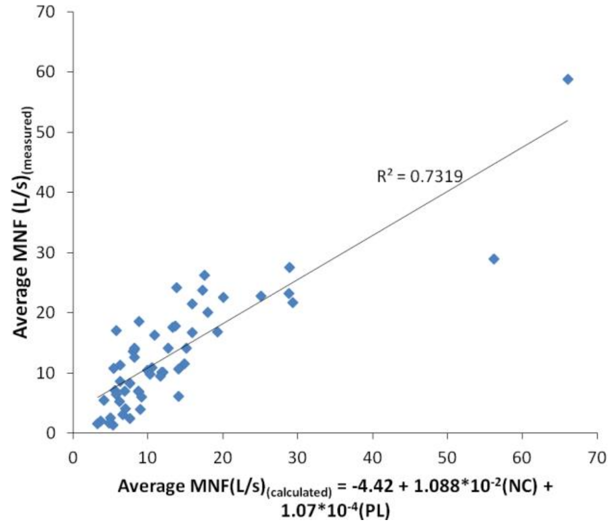


Figure 13 Relationship of MNF (L/s) to Number of Connections and Pipe Length in Melaka WDS

3.2.3 Considerations of the Influential Factors to the Water Losses

Based on the correlation and regression analysis, the results suggested that the number of connection appears to be more influential to the leakage level in Melaka WDS. Nevertheless, several studies (Alkasseh *et al.* [7], Tabesh *et al.* [44] and Weimer 1992, as stated in Skipworth *et al.* [6]) considered that length of the pipe network was the most dominant factor affecting leakage rather than number of connections. A study by Alkasseh *et al.*, (2013) in Kinta Valley, Perak, Malaysia suggested that length of the pipe network (pipe length) is a significant factors contributing to the increase in average MNF (L/s) as compared to the other factors.

Table 8 illustrates the characteristics of both study areas Melaka and Kinta Valley, Perak. Generally, in comparison with Perak, the land area of Melaka is about 1664 square kilometer, which ratio is about 0.08 from the land area of Perak (21006 square kilometer). The total network length (pipe length) and number of connections in Melaka WDS ratios about are 0.26 and 0.41 respectively as compared with Perak. From the hypotheses, we consider that population density, number of connections per unit area (per square kilometer), population served per unit length of the pipe network and the connections density (number of connections per unit length of the pipe network) are really important to determine the most influence factors affecting increase in MNF (water loss). Melaka is a compact and developing city with the population density of 525 per square kilometer, with 165 connections per unit area (per square kilometer), about 307 populations served per unit length of the pipe network, and also the connections density of 96.54. As for Perak, the population density, connections per unit area, population served per kilometer of network and the connections density are 115, 32, 224 and 61.68 respectively. The population density and connections per unit area in Melaka are 4.57 and 5.16 times more than in Perak. While as for population served per unit length of the pipe network and connections density, both are 1.37 and 1.57 times more than Perak. These ratios indicate that Melaka seems to be very packed city (might be due to urbanization and rapid population growth) as compared to a big state like Perak. Considering all these factors, thus, two types of zones can be classified in Malaysia. The first zone (Zone A) is a densely packed zone, compact with urbanization and dense settlement, high population density and connections per unit area, also high numbers of population served per kilometer of pipe network and the connections density. The second zone (Zone B) is a less compact zone, those which is not densely populated like Perak). These zones are not classified based on populous or least populated of a state (in this case Perak has higher population than Melaka), but merely based on the density of populations and connections of the pipe network within a certain area. The results suggested that as for Zone A (packed zone), like Melaka state, the MNF (water loss) values are much likely to be influenced mostly by the number of connections. Whereas based on previous study by Alkasseh *et al.* [7], for Zone B (less compact zone) like Perak, pipe length appears to be most influential to the MNF (water loss). In Zone A, the population density and number of connections per square kilometer (as compared to Perak) have led to a high number of connections (a denser network) and thus, result in increase in MNF (water losses). Moreover, higher MNF due to the denser connections (high connection density and population served per unit length of network) may also affect water losses since there are a large number of joints and fittings, which can fail and are often found to be much more variable in materials and installation practices [7, 8, 22, 23, 24]. Water losses may also increase significantly when house connections are not done properly.

The results indicatethat water utilities might need to consider several factors in water system design and during the management of water loss, as it is shown in the results that the bigger population density, connections per unit area, connection density and population served per unit length of the network, the water loss will be much more affected by number of connections in the water system.

Table 8 Characteristics of Melaka WDS and Perak [7]

	Melaka	Perak	Ratio (Melaka/ Perak)
Land Area (km^2)	1664	21006	0.08
Total pipe length (km)	2846	10792	0.26
Population	873600	2417408	0.36
Total number of connections	274758	665674	0.41
Population density (populations per unit area) (1/km^2)	525	115	4.57
Connections per unit area (1/km^2)	165	32	5.16
Population served per km of network (1/km)	307	224	1.37
Connection density (number of connections per km of network) (1/km)	96.54	61.68	1.57

4.0 CONCLUSIONS

NRW reduction needs appropriate strategic planning. Syarikat Air Melaka Berhad (SAMB) and Ranhill Water Services (RWS) representing Melaka Water Utility Company focuses in active leakage control, DMAs establishment, pressure management, asset management and also monitoring and repair works as parts of the NRW reduction program which actually drive to the effectiveness of the NRW management in Melaka WDS.

From section 3.1, it indicates that the good performance of Melaka Water Distribution System in managing NRW and water loss in the state of Melaka do improve the rate of water loss. The achieved savings before and after the commencement of the program as : minimum night flow (MNF) and net night flow (NNF) reduction of 122.42 L/s and 221.22 L/s respectively and the total leakage reduction of 17095.69 m^3/day. Furthermore, from the commencement of Active Leakage Control (ALC) program, the water utility (SAMB) managed to reduce the leakage from 25.76 percent (on January 2012) to 21.48 percent (as per March 2013). The NRW in Melaka is also observed to reduce from 32.85 percent in 2008 to 21.4 percent in 2014, much lower from average National level of NRW of 35.6 percent (2014). Melaka state is also ranked the second (after Penang state) in terms of the lowest NRW percentage. As for Melaka and Penang, despite some difference in approaches and level of interventions, both states have implemented proactive strategies in ensuring effective management of NRW.

A key of sustainable water management not only depends on effective management and reduction of water loss, but also based on a better understanding of the causes of water loss and the factors that influence it. Therefore, in this study, we analyzed the factors affecting water leakage as understanding what drives water loss is important to design proper NRW intervention.

The finding can be concluded that several network characteristics (physical factors) of the water systems such as number of connections and network length (pipe length) are statistically correlated to MNF (water loss). As for Melaka WDS, the correlation test and SLR confirmed that the coefficient (r) were 0.847 (p value 0.000) for the number of connections and 0.443 (p value 0.001) for the pipe length.

Based on the Multiple Linear Regression analysis, it can be concluded that number of connections and pipe length are the important drivers to water losses in Melaka WDS. The regression equation for average MNF (L/s) is as Equation (4):

$$\text{MNF (L/s)} = -4.42 + 1.088*10^{-2}\,(\text{NC}) + 1.07*10^{-4}\,(\text{PL}) \quad (4)$$

where the R^2 value is 73.19% while the adjusted and predicted R^2 is 72.15% and 67.44% respectively. This would be considered a good fit to the data, in the sense that it would substantially improve the water utilities ability to predict the influence factors of water loss in their distribution systems. From this model, it is indicated that an increase in 100 number of connections significantly increase average MNF by 1.088 L/s, and 10000 meter (10 kilometer) increase in length of the network (pipe length) will increase the average MNF by 1.070 L/s.

The results also suggested that in a compact, urbanized and developing city like Melaka (Zone A, packed), number of connections appears to be more influential to the increase of MNF (water loss) as compared to pipe length in the network, or in other words, numbers of connections are potential leakage points. Thus, it can be concluded that utilities located in highly urbanized and dense settlements (those with high population density and connections per unit area) are likely to experience high level of MNF (water loss) due to the increase of number of connections. In Melaka WDS, with the population density was 525 (per square kilometer) and connections per unit area was 165 (per square kilometer), which were about 4.57 and 5.16 bigger ratios than in Perak. Besides, other factors such as connection density (connection per unit length of the network) and population served per unit length of the network also need to be considered as it may also lead to increase in water loss due to the high number of connections within the area. Whereas based on previous study by Alkasseh *et al*. [7], for Zone B (less compact zone) like Perak, pipe length appears to be most influential to the MNF (water loss).

Hence, an important recommendation is that the design of non-revenue water reduction programs should study of the main drivers of water losses to provide utility managers with a better understanding of what can be achieved in terms of non-revenue water reduction strategies and this can improvise future design and operation of a distribution network. The key drivers of water losses are partly linked to the physical characteristics of water supply system especially in a city like Melaka where number of connections highly affected the water loss. Thus, besides the implementation of strategies and maintenance of the water system, the utilities should look forward to effectively minimize or reduce the number of connections in a water system and consider how design standards and settlement patterns can be taken into consideration when planning new infrastructure.

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