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Published by the Faculty of Engineering, Khon Kaen University, Thailand

Reducing water loss in a water supply system using a district metering area (DMA): A case study of the Provincial Waterworks Authority (PWA), Lop Buri Branch

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Received December 2016
Accepted January 2017

Abstract

Water loss from broken or leaking pipe networks is still a major water management problem for the Provincial Waterworks Authority (PWA) in Thailand. To reduce this loss and benefit from the savings, a district metering area (DMA) was applied as a management measure to control leaking water losses at the PWA Lop Buri Branch. The DMA was divided into 8 zones, covering about 60.47 % of the total service area. A surveillance system was set up that compared the observed flow rates and the upper limit of warning values for each DMA. Comparison of results before and after implementation of the DMA showed that rate of water loss decreased from 34.55 to 30.87 %. To further reduce these losses, sensitive warning values based on seasonal and daily patterns of water consumption were defined and implemented with an increased number of DMAs covering the entire service area. Financial analysis confirmed that the DMA measures are worth the investment because they significantly reduce the operational costs for water production.

Keywords: Non-revenue water, Water consumption, Surveillance system, Pressure management area (PMA)

1. Introduction

The World Health Organization (WHO) defines "water loss" as the amount of water lost from a water supply system where the volume, time and location of loss are unknown. If the location and amount of water lost from a broken pipe is known, then it is not truly a water loss. For the Metropolitan Waterworks Authority (MWA), the definition of water loss is the difference between volume of water distributed through its pipes and the combination of paid water bills, public use and public activities [1]. Water losses can be classified into 2 types: (1) legal losses with no recorded volume such as water for fire hydrants, inaccurate measurements by old flow meters, errors in meter reading, and, (2) illegal losses such as leakage from a pipe network, leaking and overflow from storage or elevated tanks, stolen water from connections that bypass meters and loss from broken pipes.

Management methods to control water losses consist of (1) passive leakage control, i.e., waiting for the public to report, (2) surveying to identify leaking pipes using sounding devices such as acoustic rods and listening sticks, (3) decreasing water pressure to reduce loss rate and volume, (4) waste metering. This is done by dividing a water distribution area into smaller sized sections, closing all water valves around the area, except an inflow valve, recording water flow at night and comparing this to the past minimum flow rate. If they do not coincide, a leaking pipe is assumed, and (5) forming a district metering area (DMA). Here, a water distribution area is divided into smaller zones, and a water flow meter is installed to continuously monitor inflow rate to the DMA. If there is abnormal change in the inflow rate, then there is a water loss. Recently, an optimal design of DMA was proposed by solving a three- objective optimization [2] and using graph theory principles with energy performance indices [3].

Devices required for each DMA include a flow meter, pressure meter, water valves and a data logger. Water control and management based on a DMA system provide higher efficiency than management of large area with single flow meter. In the past, the Provincial Waterworks Authority (PWA) did not realize water losses until a user reported them or it was realized from the increased volume of water produced at the end of a month.

In 2012, the water loss rates of the MWA and PWA were 26.76 % and 27.88 % respectively [4]. This study recommended that both organizations find a way to manage their water loss problem. The losses are valued at many thousand million baht per year. If such losses are reduced to an appropriate level for Thailand, great benefits will be realized. The State Enterprise Policy Office applied water loss reduction to a certain level as a criterion in performance evaluation. In the past, the water loss rate in Thailand exceeded 50%. The MWA and PWA reduced this to less than 30% in 2012 [5]. Recently, the State Enterprise Policy Office suggested that the PMA formulate a systematic management plan for dealing with water losses, both in the short and long term, together with water pressure

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doi: 10.14456/easr.2017.23

management [6]. To develop efficient operations, collaboration between the MWA, local administrative organizations and others are required to provide an integrated water production system.

A previous study showed that non-revenue water (NRW) of the MWA and PWA resulted from a leaking pipe system and stolen water [7]. The proportion of the population connected to service water pipes in the MWA is about 99%. However, it is only 18% for the PWA since they service a large area, covering 74 provinces. Construction of pipe networks in remote areas using substandard materials and poorly skilled labor increases the risk of high water losses. The cost of water production by the PWA is about five times higher than the MWA. From simulation results in 2012 for the PWA, if NRW is decreased to 0, 3, 13, or 23%, the savings will be 4328, 3886, 2330 and 774 million baht. Under these scenarios, the production costs for water will still be more than twice that of the MWA [4]. The water loss rate in Thailand is quite large compare to the 3% loss rate of Australia. The average levels of NRW in developed countries, Eurasia and developing countries are 15, 30, and 35, respectively [8]. A decrease in the water loss rate of just a few percent will result in enormous savings. For example, when Brazil installed accurate meters, water revenues increased by US$ 73 million [8]. However, the investment to solve water loss problem requires consideration of the project's economic feasibility.

A water loss reduction project using combination of DMA and a pressure management area (PMA) for the MWA, Bang Bua Thong Branch was conducted. The search time to find leaking pipes was decreased from 2-3 weeks/area to 1-2 weeks/area. This is very significant since the average loss rate for the DMA was reduced from 130 to 70 l/s [9].

Data from the PWA, specifically the Phra Nakhon Si Ayutthaya and Pathumthani branches, indicates that after DMA systems were implemented, the annual water loss in 2013, 2014, 2015 and 2016 was reduced to 33.91, 34.49, 30.48, and 27.28% for Phra Nakhon Si Ayutthaya and 35.11, 31.09, 28.36 and 27.98% for Pathumthani, respectively. The MWA invested many thousand million baht in information technology for water loss management (underground leak detection) and for a water leakage management application (WLMA). After the WLMA was implemented, the water loss decreased from 30% to 26.5% and the target is 25% [1].

The objective of this study was to define criteria for monitoring the flow rate in a water supply system after DMA implementation. It was used as a tool for water loss control and applied at the Lop Buri Branch as a case study.

2. Materials and methods

2.1 Study area

The pipe network within the service area of the PWA, Lop Buri Branch is very complex and old. The network consists of pipes in a variety of conditions including abolished, renovated and new pipes. Some pipes are easily broken and difficult to maintain.

The boundary and size of a DMA depends on the topographic conditions and the number of water users. Typical number of water users is 1,000-3,000 users per DMA [10]. The size of a DMA is limited. It cannot be too big due to it will be very difficult to locate leaking pipes. The boundary of a DMA is defined to include a minimal number of main water supply pipes to reduce the number of water control devices required, such as water valves. A more detailed discussion of DWA establishment criteria and operational guidelines are available in [10] and [11].

For the Lop Buri Branch, eight DMAs were designed and implemented, as shown in Figure 1, which covered 60.47% of the pipe network. Five new DMAs are planned in near future to increase the proportion of cover area to 76.42%. The details of the pipe system within each DMA are shown in Table 1 [12].

2.2 Primary data collection

Various types of data were collected from (1) the pipe network within each DMA and the boundary of each DMA for Lop Buri Branch, (2) the hourly time series of water inflow rates to each DMA recorded with a data logger in real time, and (3) current management problems in dealing with leaking or broken pipes.

2.3 Secondary data collection

Secondary data was collected including (1) the design, implementation and investment information for the DMA and plans for further increases the number of DMAs to increase coverage, (2) monthly reports of water production, water sale volumes and water loss rates from the office of the PWA Region 2 and the head office of the PWA. Data collection was done for before and after DMA implementation for two 14 month periods (January 2013 to April 2014 January 2015 to April 2016), respectively.

2.4 Data analysis

Data analysis included examination of (1) water management of flow rates and water pressures both before and after DMA implementation, (2) monthly and annually water loss rates both before and after DMA implementation, (3) economic feasibility of DMA implementation, (4) the management actions taken regarding pipe maintenance and repairs to broken and leaking pipe systems before and after DMA implementation.

3. Results and discussion

3.1 Relationship between a leaking pipe and surveillance

In DMA No. 8, a 200 mm pipe leaked on 21 September 2016 at 9:40 AM. The line graph in Figure 2 shows that flow rate immediately increased from 133 to 180 m^3/hr. Continuous surveillance provided for a fast response to inform fieldwork team of this problem. The water valves were closed and the pipe were repaired to quickly reduce water losses. At the moment that the pipe broke, the pressure head in the pipe (red line) was constant because the pressure was maintained by the pumping station. After the pipe was fixed, the water valves were reopened to allow normal flow. It was found that flow rate was increased as new water replenished the pipe. Shortly, the pipe system was full and the flow rate decreased to normal.

3.2 Surveillance of flow rate and pressure

Time series data of the observed hourly flow rate and pressure were compared to the past pattern of water consumption. When the current flow rate exceeds the past flow rate, it will be assumed that an abnormal condition exists and its cause will be sought. For convenience of surveillance, we defined the preliminary range of

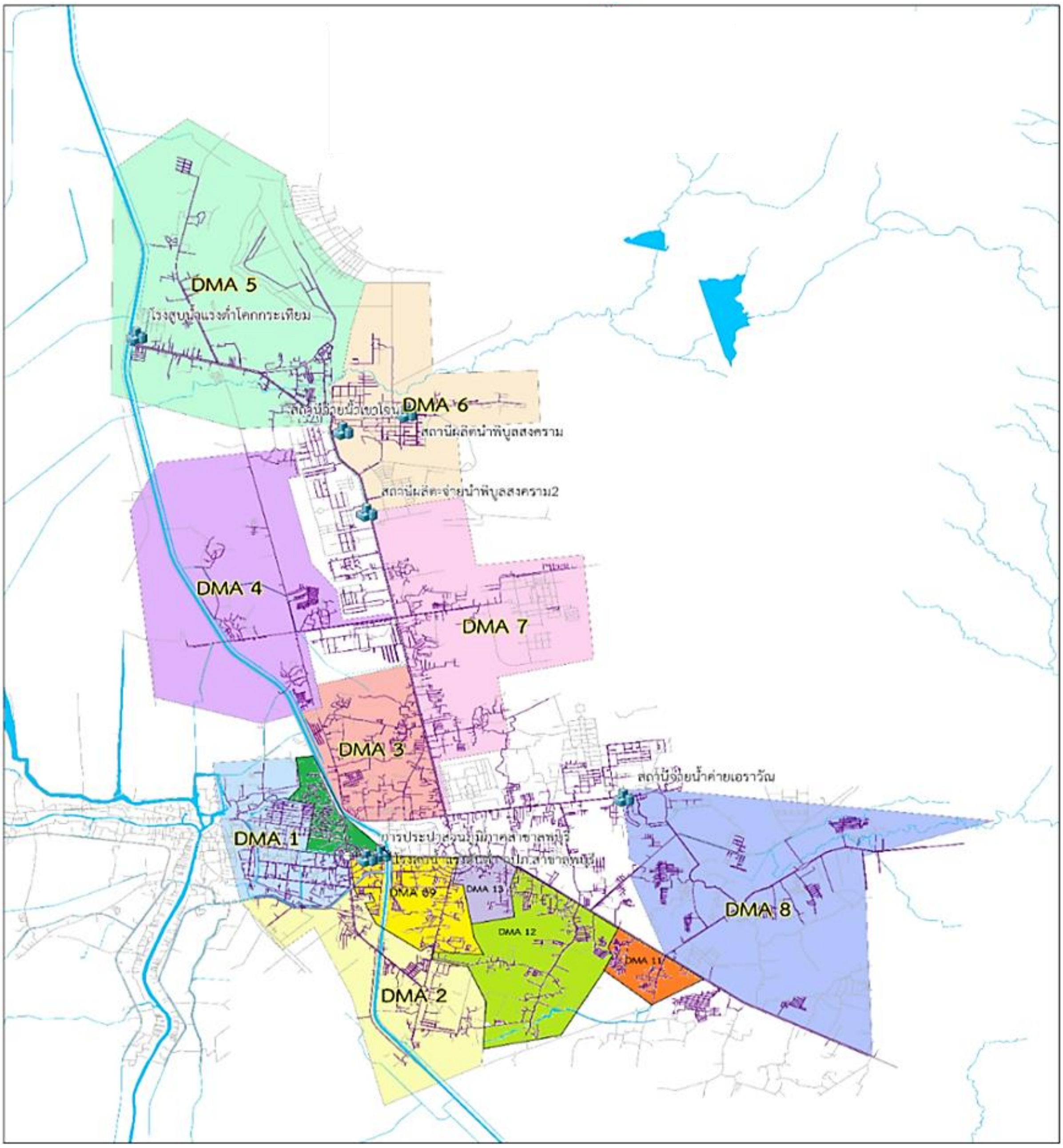

Figure 1 DMAs map for Provincial Waterworks Authority (PWA), Lop Buri Branch.

Table 1 Physical characteristics of the eight DMAs in the Lop Buri Branch

DMA zone	Area (km^2)	Water user (households)	Range of pipe size (mm)	Total length of pipe		Averaged water demand (m^3/hr)
				(m)	(%)	
1. Sakaew Circle – Sariman School	4.386	4,404	20-300	60,027	6.79	314
2. Bridge 33- Bridge Mast	9.027	2,111	25-200	49,208	5.56	168
3. Transport terminal –Erawan crossroads	6.483	3,946	20-300	76,295	8.63	158
4. Anan crossroads – DonDo Village	17.458	3,167	20-300	52,104	5.89	115
5. Pibul 2 – BoKaew Temple	16.330	2,413	20-300	85,317	9.65	140
6. Wing 2 – KhaoPhraNgam crossroads	22.512	2,146	20-300	84,365	9.54	196
7. Wing 2 - Erawan crossroads	9.107	2,016	20-300	33,778	3.82	235
8. Erawan Station	21.524	3,542	16-300	93,644	10.59	218
Total	106.827	23,745		534,738	60.47	

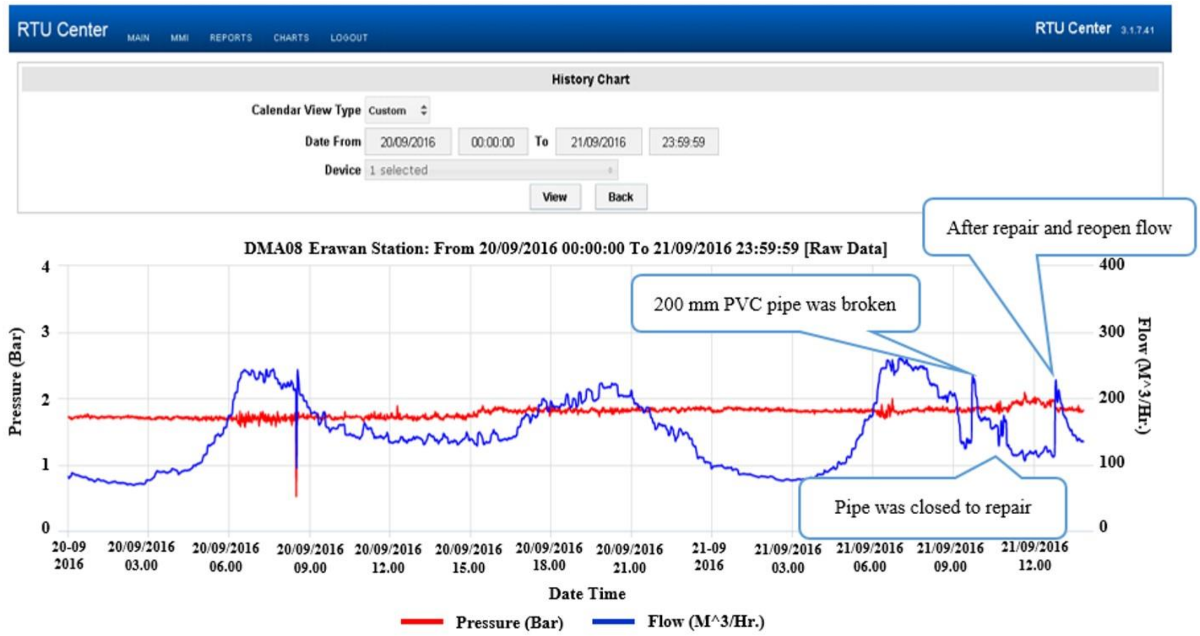

Figure 2 An example of recorded flow rate and pressure from DMA No.8, with a leaking pipe. The blue line represents flow rate and red line represents pressure.

Figure 3 An example of warning values for DMA 8, blue line represents flow rate and red line represents pressure.

warning flow rates for the system. For DMA No. 8, where the majority of land use is residential, the average peak water consumption is 300 m^3/hr at 7:30 AM and the average lowest water consumption is 80 m^3/hr at 2:00 AM (Figure 3). We used 300 m^3/hr as upper limit as a warning rate. After 7:30 AM, the water flow rate decreases due since most of water users leave their homes. If water flow rate remains high, leakage is likely. The fieldwork team will be informed and they will find the exact location of the leaking pipe and repair it as soon as possible.

3.3 Reduction of water loss rate

Before implementation of the DMA system, the observed water loss rate was 34.55 % (16 months of data). Details are shown in Table 2 and Figure 4. After the DMA system was implemented, the average water loss rate was reduced to 28.14 % or 6.41 %, lower than initial loss rate. This is 5.37 % lower than the target loss rate. The PMA set a water loss target rate equal to the initial loss rate 34.55 %. The target loss rates for the DMA over period of 6, 12, 18, 24, 30 and 36 months were 33.51, 32.47, 31.37, 29.78, 29.18 and 28.57 %, respectively.

For the 12 month period, the six month moving average of water loss rate was reduced to 30.75 % or 3.85 % lower than initial rate which was 1.77 % lower than the target rate. For the 18 month period, the six month moving average of water loss rate was reduced to 30.87 % or 0.50 % lower than the target rate. The water loss rate declined, especially in the first 6 months.

Table 2 Monthly production of water, water sales, free water, water loss volume and loss rate before DMA implementation.

No.	Month-Year	Produced water volume (m^3)	Sold water volume (m^3)	Free water volume (m^3)	Water loss volume (m^3)	Water loss rate (%)
1	Jan-13	1,830,154	1,071,982	343	757,829	41.41
2	Feb-13	1,697,995	1,089,927	457	607,611	35.78
3	Mar-13	1,896,595	1,040,579	668	855,348	45.10
4	Apr-13	1,857,565	1,171,063	2,688	683,814	36.81
5	May-13	1,922,839	1,175,957	2,922	743,960	38.69
6	Jun-13	1,835,795	1,201,765	1,206	632,824	34.47
7	Jul-13	1,680,607	1,065,004	428	615,175	36.60
8	Aug-13	1,646,173	1,088,649	617	556,907	33.83
9	Sep-13	1,639,653	1,096,345	124	543,184	33.13
10	Oct-13	1,550,458	1,026,398	103	523,957	33.79
11	Nov-13	1,600,392	1,033,997	255	566,140	35.38
12	Dec-13	1,535,963	1,049,249	375	486,339	31.66
13	Jan-14	1,527,453	1,127,703	602	399,148	26.13
14	Feb-14	1,494,760	1,118,937	977	374,846	25.08
15	Mar-14	1,508,145	1,054,326	1,375	452,444	30.00
16	Apr-14	1,738,220	1,219,720	1,750	516,750	29.73

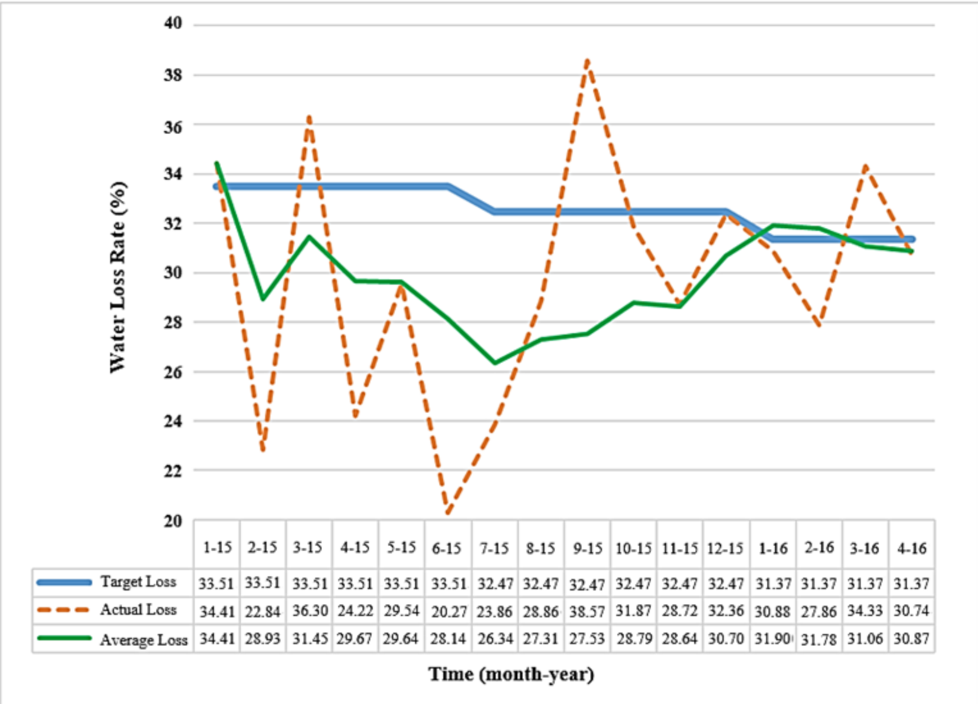

Figure 4 Monthly target losses, actual losses and moving average actual water losses after implementing DMA management.

The initial water loss rate of the Lop Buri Branch was relatively close to the loss rate of the Phra Nakhon Si Ayutthaya and Pathumthani branches. After DMA installation, the water loss rates of both branches continuously decreased for four consecutive years. However, the water loss rate of Lop Buri markedly decreased in the first year, but then leveled off and showed not further decrease after the beginning of the second year. The likely cause of this is inefficient surveillance.

For the initial stage of surveillance, the average highest and lowest flow rates were used as warning values. The pattern of water consumption and behavior of water users are always changing according to the season and the time of day. Therefore, these warning values are too coarse. Warning values should vary based on the season and time of day. With finer warning values, a small abnormal change in flow can be easily detected and more quickly affect system repairs. Forecasting hourly water demand can be done through predictive model [13].

3.4 Worthiness of DMA investment

If DMA systems are not implemented at the present time, the projected losses are 1,982,877 m^3/day (29,180,005-27,197,128 m^3/day from Table 3). When this is multiplied by the minimum unit cost of water production of 10.20 baht/m^3, a total loss of 20.225 million baht or 1.264 million baht/month is expected. The investment cost of eight DMA systems is estimated to be 4.257 million baht. The DMA investment for the Lop Buri Branch is economically feasible.

Table 3 Comparison of past loss volume without DMA, present loss volume using DMA and estimated present loss volume without DMA.

Case/Condition	Produced volume (m^3)	Sales volume (m^3)	Free Volume (m^3)	Loss Volume (m^3)	Loss rate (%)
Past Q without DMA[1]	26,962,767	17,631,601	14,890	9,316,276	34.55
Present Q using DMA[2]	27,197,128	19,077,670	20,643	8,098,815	29.78
Present Q without DMA[2]	29,180,005	19,077,670	20,643	10,081,692	34.55

Remark: [1]: January 2013 to April 2014 (14 months)
[2]: January 2015 to April 2016 (14 months)

4. Conclusions

A DMA can be used as a tool for surveillance of a broken or leaking pipe system. An operator is able to realize system problems in real time. Finding the location of a leaking pipe is easier since it is within the limited boundary of a specific DMA. Quickly fixing leaks reduces water losses.

After a DMA system is implemented, a monitoring system is set up to analyze flow and pressure data in graphical and tabular forms. These tables and graphs are compared with warning values, which are the average maximum daytime flow rates or upper limits and averaged minimum nighttime flow rates or lower limits. If an inflow rate to a DMA is detected that continuously higher than the warning value, or is not consistent with the normal pattern of community water consumption, it can be assumed that there is a broken or leaking pipe in the DMA. A field team is rapidly deployed to find its location and quickly repair it. For the current monitoring program, a warning is issued if a flow rate exceeds the warning value for more than one hour.

Prior DMA is implementation at the PWA, Lop Buri Branch, the water loss rate was 34.55%. After its implementation, during the first 6, 12 and 16 months, the moving average of water loss rates were reduced to 28.14, 30.70 and 30.87%, respectively. With a DMA system and efficient monitoring, mean times to repair of leaking pipes are shortened. In the next stage of surveillance, warning values will be refined to account for seasonal and daily fluctuations in water consumption. Better water loss assessment can be done using the minimum night flow (MNF) [14] Financial models for optimal management of water loss [15] can be used. Without a DMA system, water losses are expected to increase to 1,082,577 m^3 representing losses of about 20.225 million baht. The investment cost of a complete DMA system is about 4.257 million baht. Implementation of DMA management is a prudent and cost effective way to reduce water losses.

5. Acknowledgements

The authors are grateful to the Provincial Waterworks Authority (PWA), Lop Buri, Phra Nakhon Si Ayutthaya and Pathumthani branches for providing the water demand and DMA data used in this study.

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