Impact of Water Losses on Pressure and Energy in MWA Trunk Main Network, Thailand

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***Abstract*—Awater distribution system simulation model using the EPANET software was built to study the impact of water losses on pressure and energy in the Metropolitan Waterworks Authority(MWA) Trunk Main Network. The model was based on the MWA data in March 2013, where the percentage of water losses (%WL) = 27.45% with the average pressure of 8.66 m, and the electricity energy consumption for water distribution system was 369 MW-h/day. The MWA is suffering from high water losses and low pressure. Thus, the MWA has set the targets to reduce %WL to 19% and raise the pressure to 10.8 m in 2021. From our model results, if the MWA open the existing 130 throttled valves on its trunk mains, the pressure may increase to 9.24 m, but it impacts %WL and the energy consumption to increase as well. If the MWA couldreduce the volume of water losses, it would benefit both higher pressure and smaller energy consumption. Also, the relationships between water losses, pressure and energy were linear. Keeping the pressure provided from pumping stations and other sources constant, we found that if the MWA could reduce %WL to 19% as its target, the pressure wouldraise to 10.7 m very close to the pressure target, and it could save the electricity energy consumption of 23 MW-h/day (~30 million baht/year). Thus, water loss control and reduction programs are an effective approach when pressure improvement and energy saving are considered.**

Keywords—Water-energy nexus; Water losses; Pressure

I. INTRODUCTION

The expansion of urban area due to population and economic growth has induced an increase in urban water demands. According to [1], at present,55% of the world's population lives in urban areas (4.2 billion in 2018), and it is expected to increase to 68% by 2050 (6.7 billion). Thus, many water utilities have to cope with the rapid growth of water demand. Also, they may experience high water losses due to their old and deteriorated infrastructures, especially leakage. Since water losses cause higher discharges in water distribution systems than water demands, energy losses will increase,andthe distribution system pressure decreases. Thus, moreinput energy is necessary to provide to maintain acceptable pressure levels in the systems. A new systematic methodology to assess energy has been proposed [2]-[3].It shows that water losses impact energy losses in two ways: an additional friction energy and an outgoing energy through water losses.Theenergy assessment (sometimes called "energy audit" or "energy matrix") of water distribution systems has been studied in some countries recently [4]-[6].

The Metropolitan Waterworks Authority (MWA) of Thailand, providing potable water for Bangkok and its two neighboring provinces (Nonthaburi and Samutprakarn) is one of many utilities in developing countries that suffer from high water losses and low pressure. To deal with water losses, in 2006, MWA has redesigned its looped water distribution system to a District Metering Area (DMA) system by partitioning the existing network into subsystems with specifically defined and permanent boundaries. Thus, the volume of water lost within DMAs can be calculated, and it can guide leak detection deployment decisions to fix leaks.Other benefits from the DMA system for water loss control can be found in [7]. As a result, the percentages of water losses (%WL) reduced from 31.00% in 2006 to 24.58% in 2013 [8].

According to [6] based on the trunk main model for March 2013, the MWA had supplied the input energy to the network (excluding pumping losses) was 277 MW-h/day under %WL of 25.8%, and its 15% of the input energy was lost through leaks, and 21% was dissipated as a result of leaks by means of the additional friction. Thus, leakage is an important parameter to be considered when energy efficiency is a concern.In addition, the distribution system pressure was 8.08 m.Recently, the MWA has set the targets to reduce %WL to 19% and raisethe pressure to 10.8 m in 2021. These targets are very challenging because water losses and pressure are interrelated. Increasing pressure means higher leakage flow, and leakage is the largest portion of water losses. On the other hand, if the MWA can reduce its water losses, its pressure will raise by itself without increasing the pressure at the pumping stations. Thus, this study aims to investigate the relationship between water losses, pressure and energy of the MWA distribution system and suggest how MWA can accomplish its goal.

II. METHODOLOGY

A. MWA water distribution system

The MWA produces around 5 million m^3 per day and covers the total area of 3,195 km^2[8]. Its water distribution system consists of 4 water treatment plants, 11 distribution pumping stations, 191 km of transmission tunnels (D = 2000-

Fig. 1. Metropolitan Waterworks Authority (MWA) trunk main network [6].

3400 mm), 1,727 km of trunk mains (D = 500-1800 mm), 31,832 km of distribution pipes (D = 100-400 mm) and about 2 million service connections.

Fig. 1 shows the MWA trunk main network using in the analysis of [6] using the EPANET software.The sources are from the water treatment plants, the pumping stations andthe valve chambers, while the district meters (DMs) are the downstream ends of thisMWA trunk main network before water flowing into distribution pipe networks in DMAs. In this study, we extend this pipe network model of [6] to study the impact of water losses on pressure and energy in more details.

B. Energy balance

Table 1 shows the conceptual energy balance and components using in this study. E_{Input} is the input energy from sources. E_{Input} then turns into the output energy (E_{Output}) andthe dissipatedenergy in the network ($E_{Dissipated}$). E_{output}gets out of the network via the energy delivered to DMs ($E_{U,DM}$), the outgoing energy through water loss in DMAs ($E_{L,DM}$) or the outgoing energy through water loss on trunk mains ($E_{L,T}$). For $E_{Dissipated}$, the energy losses are due to the frictions at the DM feed lines ($E_{F,DM}$), on the trunk mains ($E_{F,T}$) and at throttledvalves on the trunk mains ($E_{F,V}$). In this study, we investigated a change of the input energy (E_{Input}) due to water losses reduction. Thus, E_{Input} can be computed as follows:

$$E_{Input} = \gamma \cdot \sum_{i=1}^{n_{Input}} \left[\sum_{k=1}^{n_t} Q_{Input\ i,k} \cdot H_{Input\ i,k}\right] \cdot \Delta t \qquad (1)$$

where i and k are indices, γ is specific weight of water, n_{Input} and n_t are the numbers of input energy feeders and time steps, respectively, $Q_{Input\ i,k}$ and $H_{Input\ i,k}$ are flow rate and energy head supplies by sources, respectively.

TABLE I. CONCEPTUAL ENERGY BALANCE AND COMPONENTS OF MWA TRUNK MAIN NETWORK.

E_{Input} Input energy	E_{Output} Output energy	$E_{U,DM}$ Energy delivered to DMs
		$E_{L,DM}$ Outgoing energy through water loss in DMAs
		$E_{L,T}$ Outgoing energy through water loss on trunk mains
	$E_{Dissipated}$ Dissipated energy	$E_{F,DM}$ Friction at the DM feed lines
		$E_{F,T}$ Friction on the trunk mains
		$E_{F,V}$ Friction at throttled valves

TABLE II. SIMULATION SCENARIOS.

Scenario	Scenario Explanation	Throttling valves	Water loss parameters
0	Base model from [6]	Yes	$C_{L,j}$
1	Remove all throttled valves	No	$C_{L,j}$
2	1st step of leak reduction	No	$0.8{*}C_L$
3	2nd step of leak reduction	No	$0.6{*}C_L$
4	3rd step of leak reduction	No	$0.4{*}C_L$

C. Simulation scenarios

As leakage is the largest portion of water losses and dependent to pressure at leaks, we assume water loss flow (q_L) in the network as

$$q_{L,j} = C_{L,j}\, P_j^{N_1} \qquad (2)$$

where j is index representing junctions having leaks on the network, $C_{L,j}$ and P_j are the water loss parameter and pressure at the junction j, respectively, and N_1 is an exponent of the relationship function between leakage rate and pressure according to the concept of fixed and variable area discharge paths (FAVAD) [9].

Table 2 shows the simulation scenarios in this study to investigate the effects of valve throttling and water loss reduction. The scenario no. 0 is our base trunk main model using the data in March 2013. According to [6], the energy loss by the friction at throttled valves ($E_{F,V}$) in the MWA trunk main network was around 13 MW-h/day (5% of E_{Input}). Throttling valves is known as an unsatisfactory practice for pressure management because it causes high energy loss and pressure drop during peak flows. But the MWA has throttled around 130 valves on its trunk mains. Since the MWA targets to increase its distribution system pressure, thus, we introduced the first scenario in which all throttled valves were fully open while all pressures at the sources and the water loss parameter (C_L) were kept at their original values. Then, the following scenarios were the reduction of water losses from the scenario no. 1 by decreasing C_L by 20% for each step.

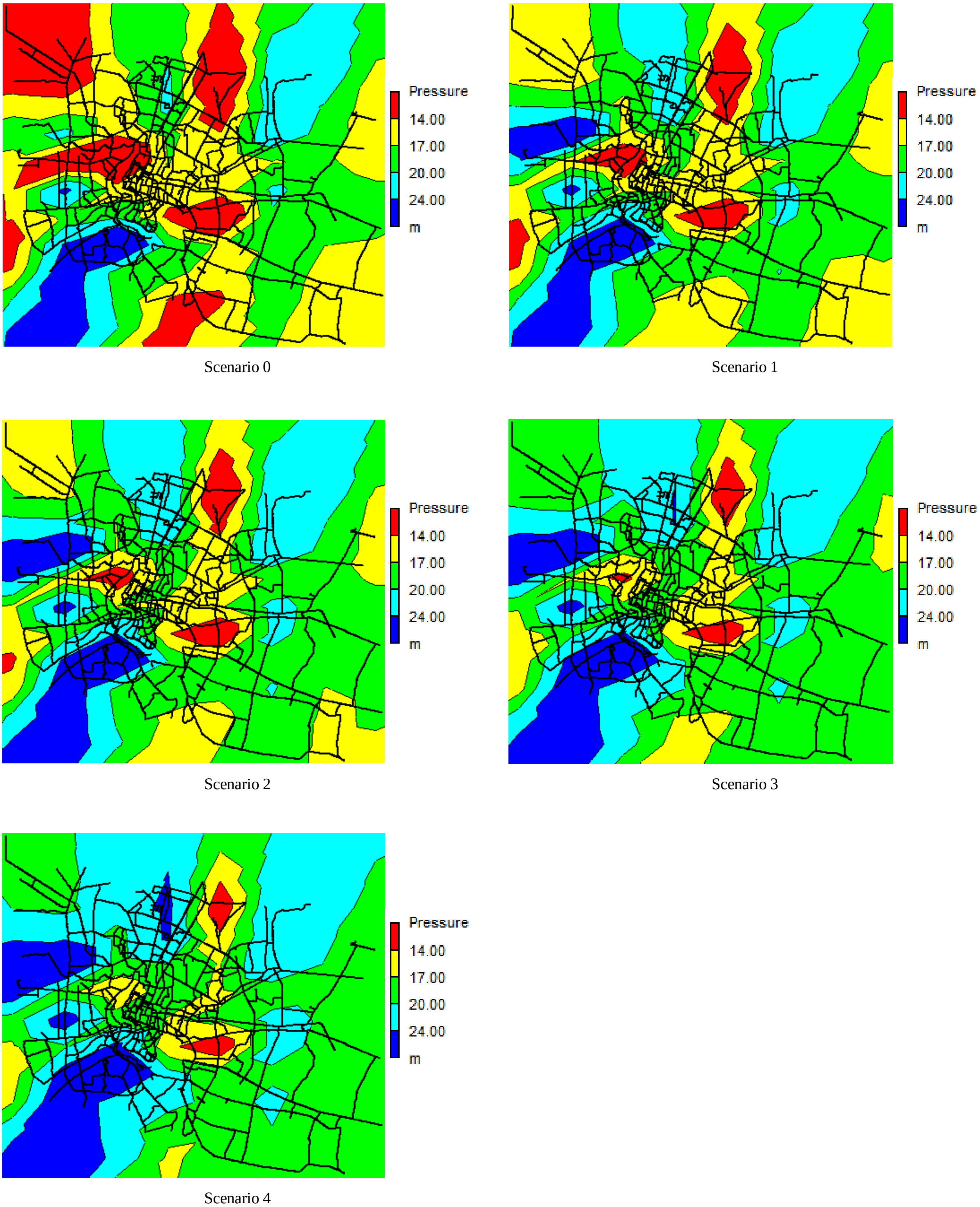

Fig. 2. Pressure distribution during peak time (7:00 am) for each simulation scenario

TABLE III. RESULTS OF WATER LOSSES, PRESSURE AND ENERGY.

Scenario	Volume of water losses, WL (MCM/day)	Percentage of water loses, %WL (%)	Average Pressure (m)	Range of Pressure (m)	Input Energy, E_{input} (MW-hr/day)
0	1.422	27.45	8.66	4.25 - 10.70	270
1	1.526	28.89	9.24	4.40 - 11.73	289
2	1.295	25.63	9.74	4.55 - 12.49	277
3	1.036	21.61	10.33	4.72 - 13.39	264
4	0.741	16.48	11.02	4.92 - 14.49	249

III. RESULTS AND DISCUSSION

A. Pressure distribution

According to the United States recommended standards for water works [10], the normal working pressure should be at least 35 psi (~24 m), and the minimum pressure in a distribution system should not be less than 20 psi (~14 m) under all conditions of flow. Fig. 2 show the pressure distribution results of the MWA trunk main network during peak time (7:00 am) for all scenarios. It can be found that the MWA normal working pressure is lower than the US recommended standard. In addition, there are some areas that the pressure is lower than 14 m (the minimum requirement under the US recommended standards). However, this range of pressure is quite common in developing countries. For example, the Manila standard recommends the minimum pressure of 7 psig (~5 m) [11].

Comparing the pressure distributions between the scenarios 0 and 1 in Fig.2, we can see that the pressure raises significantly if the throttled valves are open. The pressure in the southern and northwestern service areas turn to be higher than 14 m, and the western area that has pressure less than 14m shrinks considerably. As the water losses reduce in the scenarios 2, 3 and 4, the pressure distribution improves gradually, and, finally, there are only the northern and central areas that have the pressure less than 14 m. For the northern area, it is due to that there is no pumping station close to the area, so a high energy loss occurs during the delivery. For the central area, one pumping station operates with pressure lower than 20 m causing low pressure in its corresponding area.Also, there were only 7 pumping stations from all the distribution system sources that operate with pressure higher than 24 m (the US recommended normal working pressure).In conclusion, opening the throttled valves and reducing water losses both help to improve the pressure distribution.

B. Water losses vs. pressure and energy

The results of water losses, pressure and energy for each scenario are shownin Table 3. An average of the 24 hourly pressure in every scenario was lower than the pressure during peak time, and it was also less than 14 m. It is because the MWA has applied the pressure management, in which the pressure at the sources reduces during off-peak time. Moreover, in some areas, the pressure was even lower than 5 m. According to [12], "Loss of Pressure Boil Water Advisory" (boiling tap water before drinking) are commonly issued in the US when system pressure drops below 20 psi(~14 m).It is because microbial contaminants can enter the distribution system's water supply if a drinking water pipe is hydraulically connected to a contaminant source, and the pressure in the pipe drops to a level below that of the contaminant source including backflow, groundwater, water in repair trenches, and water in below-grade air-valve vaults [12].In addition, Michigan Department of Environmental Quality (DEQ) [14] advised that after a low pressure event (5-20 psi) is over and normal pressure is restored, the impacted area should be thoroughly flushed and coliform samples should be taken throughout the area to determine if the distribution system is free of any bacteriological contamination. However, if pressure drops below 5 psi (~3.5 m), DEQ defines it as a complete loss of pressure or negative pressure in the distribution system.After pressure is restored and the system recovers (tanks are filling, and enough sources are operating to ensure pressures do not drop again), the affected area should be thoroughly flushed and coliform samples must be taken throughout the area to determine if the distribution system remains free of coliform contamination.From our results, there are some points on the trunk mains that have pressure below 5 m. Thus, it is possible that pressure is sometimes below 5 psi (~3.5 m) in some areas on the MWA distribution pipes. As a result, the MWA distribution system is operating pressure lower than the US and other developed countries practices [13] that might cause potential contamination risk.

Comparing the scenarios 0 and 1 for the case that the throttled valves on the trunk mains were open, the volume of water losses (WL) increased 0.104 MCM/day,and the percentage of water losses (%WL) increases slightly from 27.45% to 28.89%because the system pressure raised. Also, the input energy increased around 20 MW-hr/day due to higher system flow from an increase in water losses. The FAVAD equation in (2) actually imitates an orifice flow equation under pressure. So, the water loss parameter $C_L$in (2) is a function of leakage area.Reducing C_L by 20% for each stepfrom the scenarios 1 to 4 implies leakage area in a pipe network system decreased by 20%. However, the results show that the volume of leakage dropped less than 20% for each step because system pressure increased due to less energy losses and affected water loss flow in (2). Unlike the case of opening the throttled valves, the benefits on both pressure and energy can be clearly seen if the MWA can reduce water losses. These results are just

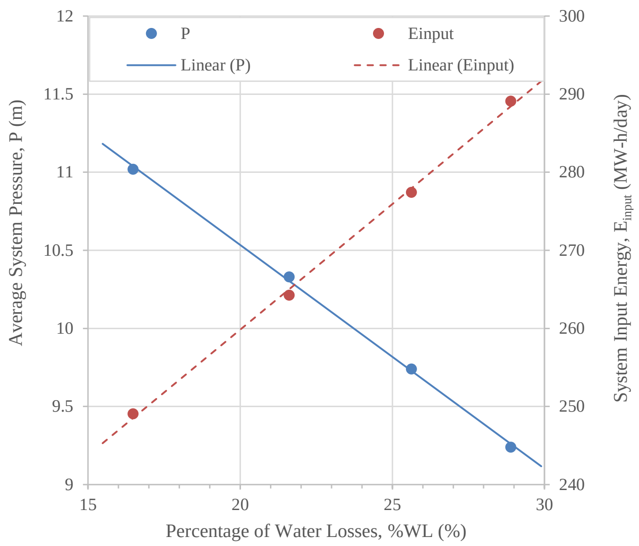

Fig. 3. Relationships between percentage of water losses, average system pressure and system input energy.

another example to support any utilities to concentrate on controlling and reducing water losses especially leaks if they want to save energy effectively and economically [15].

C. *MWA targets of presure and water loss*

Fig. 3 shows two linear relationships between the percentage of water losses (%WL), the average system pressure (P) and the system input energy(E_{input}) for the MWA trunk main network. As described earlier, the MWA has set the targets to reduce %WL to 19% and raisethe pressure to 10.8 m in 2021.Although our simulation results were originally based on the MWA data in March 2013, it might provide some important information on how the MWA could approach the targets. If we set %WL of 19% and estimate P and $E_{input}$from the figure, we will get P = 10.68 m and E_{input} = 253.8MW-hr/day. Thisresult implies that if the MWA could reduce %WL to 19%, the pressure may raise to almost 10.8 m by itself without a need to increase the pressure at the sources such as pumping stations. In addition, E_{input} reduced 16.1MW-hr/day. According to [6], the electricity energy consumption for water distribution system was 369 MWh/day in March 2013, and the ratio between the input energy and the electricity consumption was estimated to be 0.70. Thus, if the 2021 targets were met, the MWA could save the electricity consumption of approximately 23 MW-h/day (= 16.1/0.7). However, when we back-calculated the value of the water loss parameter that matched %WL of 19%. We found that it equals to 0.50C_L. It can be said that the MWA might have to fix its leaking pipes and other types of water losses to achieve the reduction of leak area by around 50% of the total leak area based on the situation in March 2013. Thus, these targets are very challenging.

IV. CONCLUSION

The Metropolitan Waterworks Authority (MWA) is responsible for providing potable water for three provinces in Thailand: Bangkok, Nonthaburi andSamutprakarn. Its trunk mains network is comprised of 1,700 km of 500-1800 mm trunk mains, 4 water treatment plants and 11 distribution pumping stations. In March 2013, the system input volume (SIV) was 5.18 MCM/day, the water losses (WL) was 1.34 MCM/day (%WL = 27.45%) with the average pressure of 8.66 m, and the electricity energy consumption for water distribution system was 369 MWh/day. Using these data, the MWA trunk main network model was built and calibrated. The MWA has set the targets to reduce %WL to 19% and raise the pressure to 10.8 m in 2021. Since the MWA water losses are mainly leakage, directly depending on pressure, the achievement of both targets is rather difficult. The MWA has throttled 130 valves on its trunk main network to reduce WL and control flow, however, causing an adverse effect on pressure and energy during peak demands. Our analysis (based on the March 2013 data)found that if the input pressure at all sources remains the same but all throttled valves are open, %WL and the pressure may increase to 28.9% and 9.24 m, respectively. Then, if MWA can find and fix leaks and reduce %WL to 19% as its WL target, the pressure will raise to 10.7 m almost equal to its pressure target without increasing its pressure at the sources. The other benefits are that SIV will reduce 0.434 MCM/day, and the electricity energy consumption may reduce around 23 MW-h/day. According to the Metropolitan Electricity Authority [16], there are two types of tariffs for the large general service type including MWA: Time of Day Tariff (TOD) and Time of Use (TOU) Tariff. The energy chargeranges from 2.6107 to 4.3555 baht/kW-hdepending on the type of tariffs and the usage time (off peak and on peak times). Using the average value of 3.5 baht/kW-h, the reduction of energy consumption could be worth roughly 30 million baht per year (900,000 USD/year) for MWA.

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