POTENTIAL OF WATER AND ENERGY SAVINGS IN BANGKOK WATER SUPPLY SYSTEM, THAILAND

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ABSTRACT

Water is used to produce energy and energy is also needed to produce water and hence they are closely linked. Ever increasing demand of water and energy requires us to find ways to conserve these resources. This study aims to evaluate the current energy use in water supply system of Metropolitan Waterworks Authority (MWA) and analyzes several alternatives to conserve water and energy. A pilot area, DMA 15-03-02, has been selected for the purpose. Five alternatives considered in the study are: Alternative 1 (decreasing service pressure), Alternative 2 (decreasing base demand), Alternative 3 (decreasing service pressure using hydro turbine generator) Alternative 4 (increasing service pressure) and Alternative 5 (increasing service pressure with pressure reducing valve, PRV). The secondary data of water production and energy consumption of MWA has been collected. The energy use in each stage of MWA is as follow: raw water intake 0.0097 (4%), water treatment 0.0469 (20%), water transmission 0.0961 (41%) and water distribution 0.0811 (35%). The energy use in the pilot area is estimated to be 0.1765kWh/m^3 by MWA and 0.5kWh/m^3 by customer, respectively. Decreasing in current service pressure indicates that water can be conserved while increasing the supply pressure would affect energy use. Using hydro turbine can reduce pressure and also generate the electricity which can be used for another purpose. Moreover, PRV installation can help reducing leakage 20-25% in case of high pressure. Further, the analysis suggests that increasing pressure up to 18m with PRV can reduce total energy use by 32% (from 0.6765 to 0.4613kWh/m^3).

Keywords: water-energy nexus, water supply system, Bangkok, energy saving.

1. INTRODUCTION

Water and energy are intrinsically related. Many of the technical processes of extracting and producing energy utilize much water. For example, water is used to cool steam electric power plants fueled by coal, oil, natural gas and nuclear power. Water is also used in great quantities during fuel extraction, refining and production. On the other hand, water extraction, treatment, and distribution processes consume energy. Significant energy is also used for the treatment and disposal of wastewater. Further, energy is also consumed when water is used by households and industry, especially through heating and cooling. Table 1 presents the range of energy usage in the various stages of the water supply in a typical water utility in California, USA, while Figure 1 depicts the amount of water used to produce energy from a variety of sources.

Table 1: Range of energy usage in various stages of water supply (data: Californian water utilities)

Water-Use Cycle Segment	Range of Energy Intensity kWh/MG	
	Low	**High**
Water Supply and Conveyance	0	14000
Water Treatment	100	16000
Water Distribution	700	1200
Wastewater Collection and Treatment	1100	4600
Wastewater Discharge	0	400
Recycled Water Treatment and Distribution	400	1200

(Source CEC, 2005)

The interconnection between water and energy is called the "water–energy nexus", and now has become one of the most significant issues in contemporary policy circles. A change in one of the 'nexus' parameters, is bound to have repercussions on the latter. There are many compelling economic and political drivers for better understanding and prudent management of the water-energy nexus. The World Business Council has declared "To find sustainable solutions (to global natural resources problems) we must ensure that we address water, energy and climate change in a holistic way. It is not practical to look at them in isolation. When you have an energy problem, you have a water problem and vice versa" (Kenway, 2013). The current rate of population growth and a strong possibility of increased future growth cast serious challenge for water and energy security (World Economic Forum, 2011).

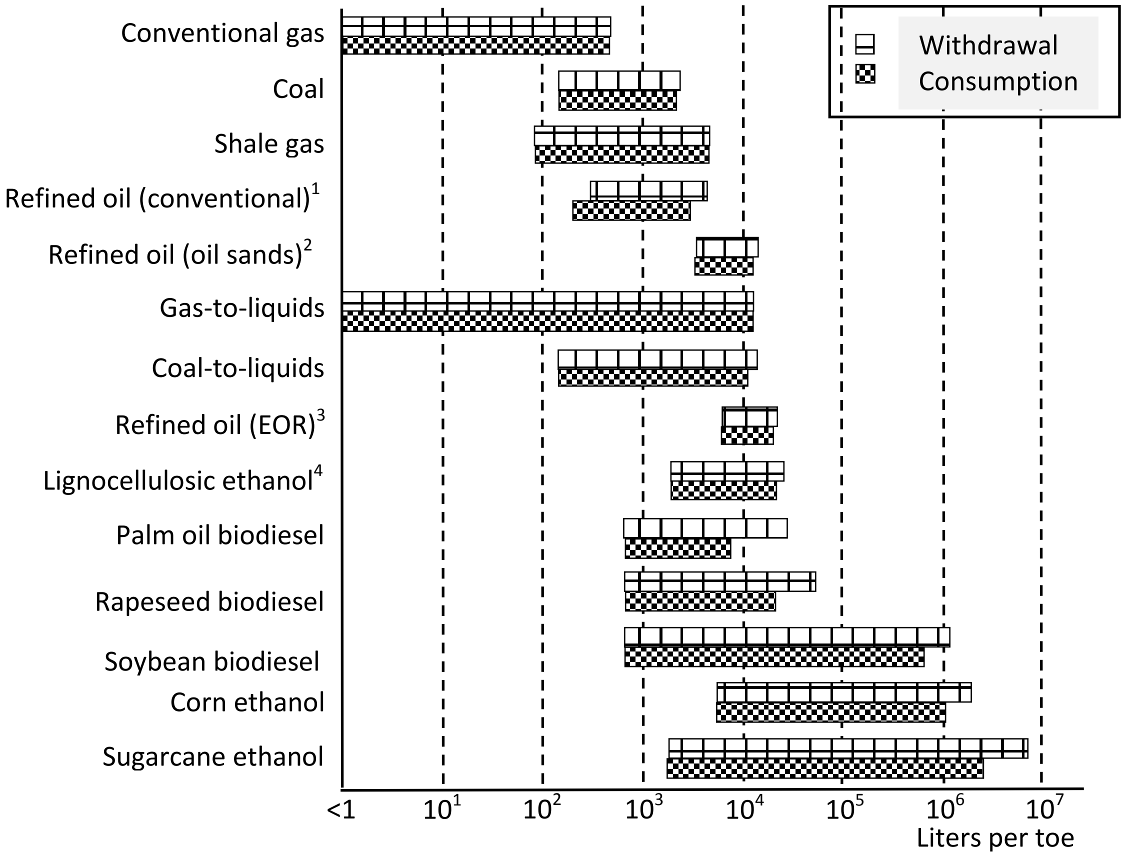

Figure 1: Water used for primary energy production (Source: IEA, 2012)

Various studies (e.g. Kenway et al., 2013) have revealed that there will be a continued sharp increase in population in the future, which will reduce per capita availability of water, necessitating alternative water supply processes, which could be more energy-intensive; increasing energy consumption by up to 600%). This increasing energy demand and decreasing freshwater supply in many areas will lead to water and energy scarcity problems. Thus, it is important to better understand patterns of resource use and the vulnerability of its growth to resource scarcity. Water and energy policy, planning and management must be integrated to encourage conservation, motivate innovation, and ensure sustainable use of water and energy. End users, such as businesses and households, also have an important role to play. By reducing the amount of water they consume, end users conserve not just water but energy, too. Similarly, by reducing the energy usages, end users conserve not only energy but water, too.

More than half of the world's population lives in Asia, but it has less per capita freshwater than any other continent except Antarctica (Asia Society, 2009). Unlike energy resources, water has no substitute and has been recognized as a unique resource, and it is clear that the management of water resources is not as easy as it was in the past (World Economic Forum, 2011). It is important to incorporate the energy associated with water use to ensure future availability of water resources while fulfilling present needs (Shrestha et al., 2012). At present there is a need for the integration of water and energy policies into a framework for sustainable use of water resources (IWA, 2009). Reducing energy consumption and GHG emissions from the water sector should be considered as one of the goals for sustainable water consumption and production in cities to reduce carbon footprint (Shrestha et al., 2012).

This paper describes a case study in Thailand with the intention of exploring the inter-linkage between water and energy, and has been entitled **"Analysis of water and energy conservation alternatives in Bangkok water supply system, Thailand"**

Thailand is currently facing major energy problems in many sectors due to insufficient natural resources and environmental protection considerations. Each year Thailand has to depend on imported energy from foreign sources which significant financial implications. Over the past decade, the energy consumption in Thailand by the water and wastewater sector has increased considerably as a result of population growth, climate change, urbanization and rising health and environmental standards requirement. The price of energy has also substantially increased in the same period. The water supply stakeholders are on the lookout for approaches that seek to reduce energy consumption in water supply systems. A number of potential interventions have been proposed over the years. For instance, capturing and reusing storm water runoff can greatly reduce the consumption of water as well as the energy usage and CO_2 emissions. Similarly, during distribution of water in supply network, pressure management is an effective means to reduce loss of water and energy. The choice of the most appropriate intervention will depend upon many factors such as topography of the service area, characteristic of the distribution network, type of treatment targeted, consumer behavior, and institutional and policy regulations. While the consideration of all these factors is an arduous task, useful insights can be gained if selective options with limited scope of interventions are studied. This study is aimed at examining options to reduce the water and energy consumption by modeling potential scenarios pertaining to the minimum service pressure and consumer base demand. A particular District Metering Area (DMA) of the largest water utility is Bangkok, Metropolitan Waterworks Authority (MWA), was selected for this purpose.

2. STUDY AREA DESCRIPTION

MWA is a state-owned water utility responsible for supplying drinking water to the capital of Thailand, Bangkok, and its neighboring vicinities. The missions of this organization are threefold: (a) tapping into new raw water sources, (b) producing and delivering good quality of tap water to about 11 million people in Bangkok and its suburbs Nonthaburi and Samut Prakan province, and (c) continue to manage and operate the MWA enterprise for the benefit of the Thai people and the nation. The intake sources of the MWA water supply system are the Chao Phraya and the Mae Klong Rivers. The use of groundwater in Bangkok is illegal due to its tendency to cause ground settlement. Water is pumped from the two rivers through three intake pumping stations (Ta Muang, Bang Len and Samlae), and channeled via canals to the various treatment plants. Each of the pumping stations have water quality monitoring systems to ensure that the quality of the raw water conforms to predetermined standards. MWA owns and operates four water treatment plants—Bang Khen, Samsen, Thonburi and Mahasawat—which can produce up to 4.76 million m^3 of treated water per day. There are 15 distribution pumping stations (Bang Khen03, Bang Khen03, Mahasawat, Sam Rong, Lumpini, Klong Toey, Lat Krabang, Lat Praow, Phahonyothin, Min Buri, Bang Pli, ThaPra, Ratchaburana, Phetchakasem and Prachanukul) for transporting the water to serve almost 2 million customers within MWA's service area. In term of service coverage, about 93% of the population in MWA service area is connected to the MWA supply system. The non-revenue water (NRW) of MWA is 25.26% (MWA Annual Report, 2011).

The locations of the treatment plants and the distribution pumping stations are shown in Figure 2. At present, the service area covers 2,477 km^2 and is divided into 16 branches or 926 DMAs for improving the management efficiency in water provision, customer services, pipe and valve repairs, meter replacement, meter recording, bills collection and other related services. DMAs are often used as a tool to control and drive down leakages in water networks. By dividing the distribution system into smaller, easier to manage and monitor areas, DMAs help to determine which parts of the network experience the highest level of leakage, through minimum hour or minimum night flow analysis. The inflow and out flow in the isolated distribution system is recorded through flow meters at a control point. The rationale for the DMAs is based on the premise that if there is unjustified increase in water usage in a particular area, there is a strong possibility that leakage has occurred in that area. Therefore, resources can be targeted to the affected area, and leak detection activities can be directed to pinpoint the leakage. DMAs can form an integral part of the leakage control strategy for many water utilities either through permanent infrastructure installations or temporary measurements.

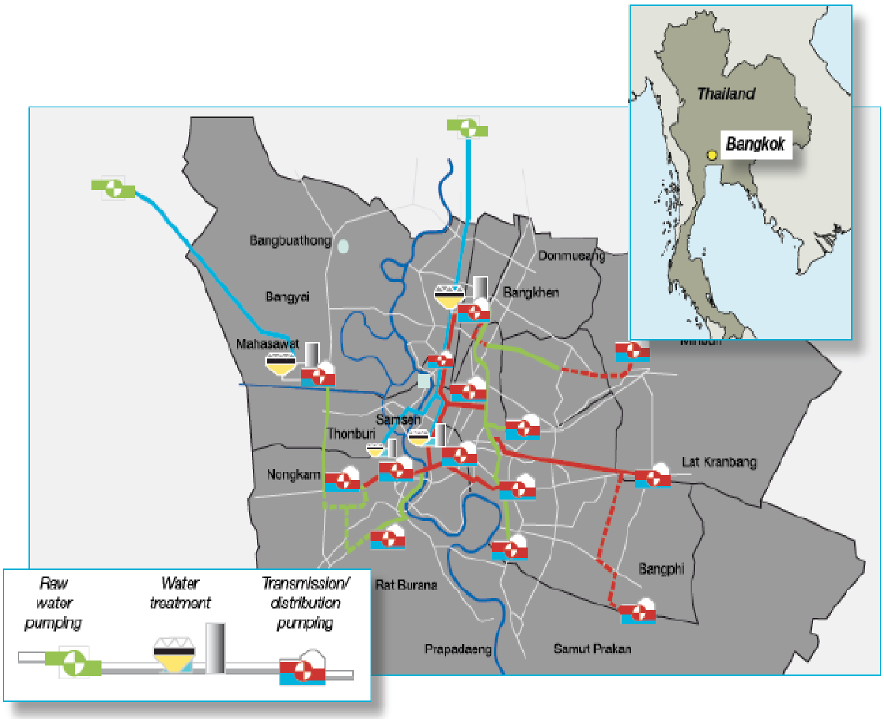

Figure 2: MWA service areas and treatment plants(Source: ADB and MWA, 2009)

The supply of treated water, and the corresponding water consumption, in the MWA system varies greatly during the day. Consequently, pumps transferring water from the treatment plant to the distribution pumping stations often run at partial load. This results in enormous amounts of wastage of energy. Further, because over the years MWA has become a large service organization in a growing urbanized area, the energy consumption has been on the rise, and any wastage only compounds the problem. Therefore, reducing energy use, and mitigating the resulting environmental impacts, is an important issue in MWA's future strategic policy considerations.

Until now, there have been no significant studies on evaluating the energy consumption in various steps of MWA's water supply cycle, from raw water pumping to supplying water to consumers. Such a study of the energy consumption assessment is required to initiate and deploy energy resources more efficiently and will help in identifying the approaches and measures needed to conserve energy, protect the environment, and also reduce water production costs. Apart from benefits to the utility, such efforts will have larger social and environmental impacts as well; with the quality of life of people improved.

3. METHODOLOGY

The primary objective of this study was to evaluate MWA's options for water and energy conservation. To be able to do so, first data with regards to existing energy and water use was collected from the utility. This data was used to perform water/energy audits, which would provide a useful background for the subsequent study. Next, a hydraulic network model, using EPANET2 software (Rossman, 2000), was developed for a pilot area in order to simulate the water flow and pressure behavior, and use these values to calculate the water and energy conserved in the water distribution system of the pilot area. EPANET is a Windows 95/98/NT program that performs steady state and extended period simulation of hydraulic and water quality behavior in pipe networks. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and concentration of a chemical species throughout the network during a multiple time steps. EPANET was developed by the Water Supply and Water Resources Division (formerly the Drinking Water Research Division) of the U.S. Environmental Protection Agency's National Risk Management Research Laboratory. It is a public domain software.

A specific DMA (DMA 15-03-02) was selected for the modeling study so as to have well defined boundary conditions, and control over the study. Figure 3 shows the schematic of this DMA.

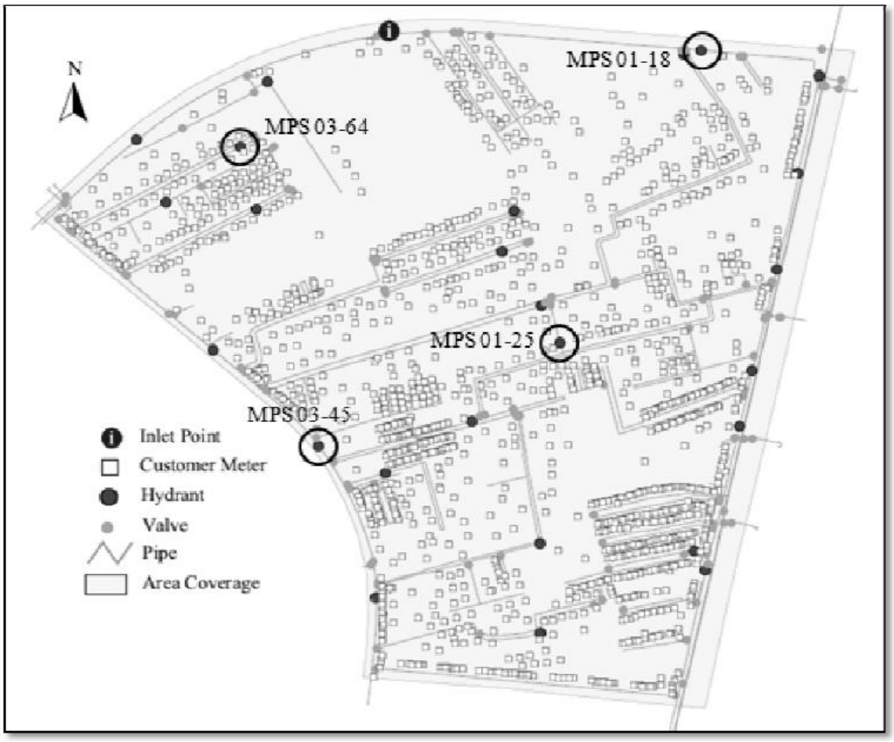

Figure 3: Network of selected DMA for hydraulic modeling (DMA-15-03-02), showing the inlet point and calibration points (MPS: Mobile pressure sensors)

The data required for developing the hydraulic model is presented in Table 2. The input data in order to run the simulation included: Pressure and discharge in every 1 hour for 10 days (simulation period) at the inlet point of study area; and demand pattern for each type of customer.

Table 2: Data description for network model for selected DMA (DMA-15-03-02)

Particular	**Unit**	
Pipe length	km	25.21
Number of pipes	number	316
Pipe diameter	mm	25, 50, 100, 150, 200, 300
Pipe material	type	Asbestos cement, ductile iron, galvanized iron, polybutylene, polyvinyl chloride, steel
Valve	type	Flow control valve
Installation year of fixtures	year	1967–2012
Number of metered connections	number	1, 310
Number of inlets	number	1
Number of outlets	number	0

In the hydraulic model, two types of demand were assigned to each node, namely consumer demand or base demand, and leakage demand. Consumer demand was categorized into six types (residence; residence and condos; nightclubs and restaurants; institutes/offices; schools; and construction sites). The average base demand for each household node was calculated from the monthly water consumption records.

The other type of demand is leakage demand or pressure dependent demand. Generally, in EPANET2.0, appropriate emitters coefficients are used for modeling the pressure dependent component of demand. The emitter coefficient assigned to the model depends on the age of the pipe installation which directly affects the leakage in the network. An emitter coefficient is the power exponent of the loss-pressure relationship. If the pressure exponent can be measured with good accuracy, then that value can serve as an emitter coefficient. In this study, emitter coefficient was initially assigned from the value of the pressure and leakage relationship. Because this value is not exact it was also used as a calibration parameter in the model. Apart from emitter coefficient, pipe roughness has also been used as a calibration parameter. The pipe roughness assigned takes into account two conditions: pipe material, and installation year (to ascertain average pipe age). Flow and pressure at the inlet point and four sampling locations were checked during the calibration. To increase the reliability of the model, same level of emphasis was given to the validation of the model. Validation was done with different data for daily inlet flow and pressure profile in a different month of the year.

In this study, the alternatives were developed in order to explore options of water conservation, energy conservation, and reducing energy use per cubic meter of water. The alternatives considered in the study are presented in Table 3.

Table 3: Alternatives analyzed for water and energy conservation

Alternatives		Description
A0	Base case	Fixed minimum service pressure 7.5m, with 100% base demand.
A1	Pressure management (Reduce service pressure)	Reduce minimum service pressure to 3, 5, 6 and 7m, with 100% base demand.
A2	Demand management (Decrease base demand)	Reduce both base demand to 80, and 90% of base demand; and minimum service pressure to 5, 6, 7 and 7.5m.
A3	Energy generator (Decrease service pressure with turbine generator)	Use hydro turbine generator to generate energy with minimum service pressure of 5, 6 and 7m and with 80, 90 and 100% base demand.
A4	Pressure management (Increase service pressure)	Increase minimum service pressure to 9, 12, 15, 18 and 21m, with 100% base demand.
A5	Pressure management (Increase service pressure with PRV)	Use Pressure Reducing Valves to fix the minimum service pressure at 12, 15, 18 and 21m, with 100% base demand.

4. RESULTS AND DISCUSSION

(a) Existing trend of water and energy consumption in the MWA: To develop a better understanding of the choices of water and energy conservation, first there is a need to ascertain the existing water and energy use in the system. Figure 4 shows the trend of raw water pumped, water treated, water produced and water actually consumed by the customers for MWA from 2004 through

2011.

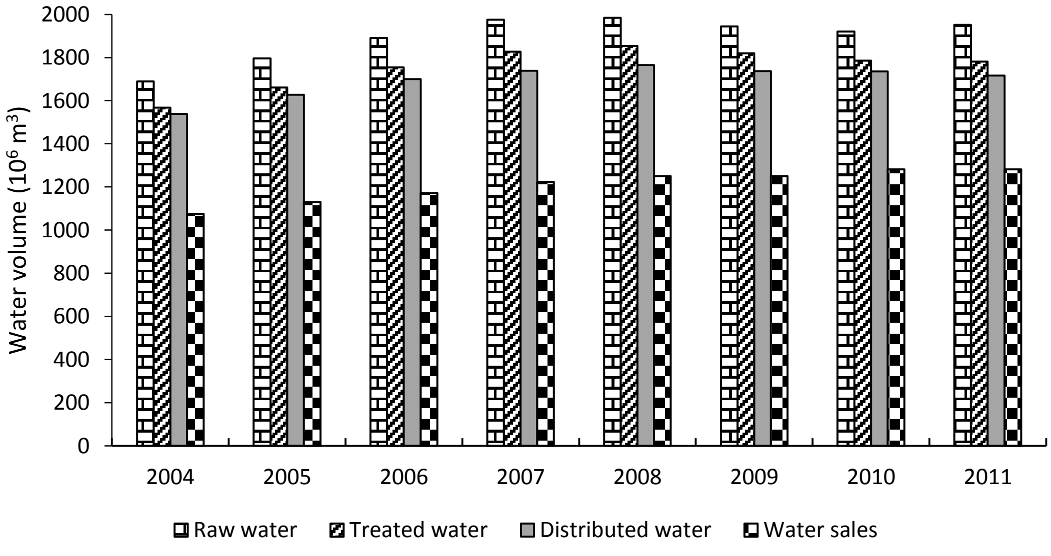

Figure 4: MWA's water production (2004–2011

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The volume of pumped raw water approximately increased by 100 MCM per year from 2004 to 2006, but there was only a slight change from 2006 to 2011 (the raw water volume pumped during this period averaged 1,950 MCM). The treated volume of water and volume of water distribution also shows the same trend. The treated water volume rose gradually from 1,600 MCM in 2004 to 1,800 in 2006. From 2006 to 2011, this volume was maintained approximately uniformly at 1,800 MCM. Similarly, the distributed water volume also went up from 1,500 MCM in 2004 to 1,700 MCM in 2006, after which it attained a uniform value. The water sales rose gradually every year approximately from 1,100 to 1,300 MCM. The difference between the water produced and sold would be the water lost in the supply distribution system. The water loss in raw water intake process results from seepage and evaporation in the canal conveyance. In treatment plant, the water loss is mainly due to the wastage in back wash and draining of sludge. The water loss at the last stage before end user is called non-revenue water which is from unbilled authorized consumption, apparent losses and real losses. Table 4 presents a comprehensive water accounting in the MWA water supply system.

Table 4: Water balance and per capita use in each stage of MWA's supply cycle

MWA Water supply stage	Average (2004–2011)		
	Volume (10^6 m^3)	% Proportion	Per-capita (L/day)
Raw water intake	1,894.4	100	659.7
Losses in raw water canal	137.6	7.3	47.9
Water treatment	1,756.8	92.7	611.8
Losses in treatment process	61.9	3.3	21.5
Water distribution	1,694.9	89.5	590.3
Water production	1,694.9	89.5	590.3
NRW	486.3	25.7	169.5
Water sales	1,208.6	63.8	420.8

Similarly, Table 5 provides a detailed breakdown of the energy usage in the MWA's supply cycle, where it is seen that the maximum energy is consumed during the water transmission phase (41.1% of the total energy use). The proportions of energy consumption to total energy consumption in the remaining phases in decreasing order of energy consumption are: water distribution (34.7%), water treatment (20.1), and raw water intake (4.1%).

Table 5: Average proportional energy consumption in each process of MWA's water cycle

Process	Average (2004 – 2011)		
	Energy use (kWh/m^3)	Energy cost (Baht/m^3)	Proportional energy use (%)
Raw water intake	0.0097	0.0257	4.1
Water treatment	0.0469	0.1136	20.1
Water transmission	0.0961	0.2490	41.1
Water distribution	0.0811	0.2244	34.7

(b) Calibration and validation: Based on the methodology outlined earlier, calibration and validation of the model was carried out by comparing the measured and simulated water flow and pressure at selected points in the network. Both the 'flow' and 'pressure' parameters were considered in these activities, examples of which are shown in Figure 5. It can be seen that there is a very good fit between the observed and simulated parameters in both calibration and verification. For example, in calibrating the pressure parameter, the Efficiency Index was 0.99, Root Mean Square Error was 76.5 m^3/day, and Mean Absolute Percentage Error was 2.17%. The error in verification for both flow and pressure parameters was below 2%.

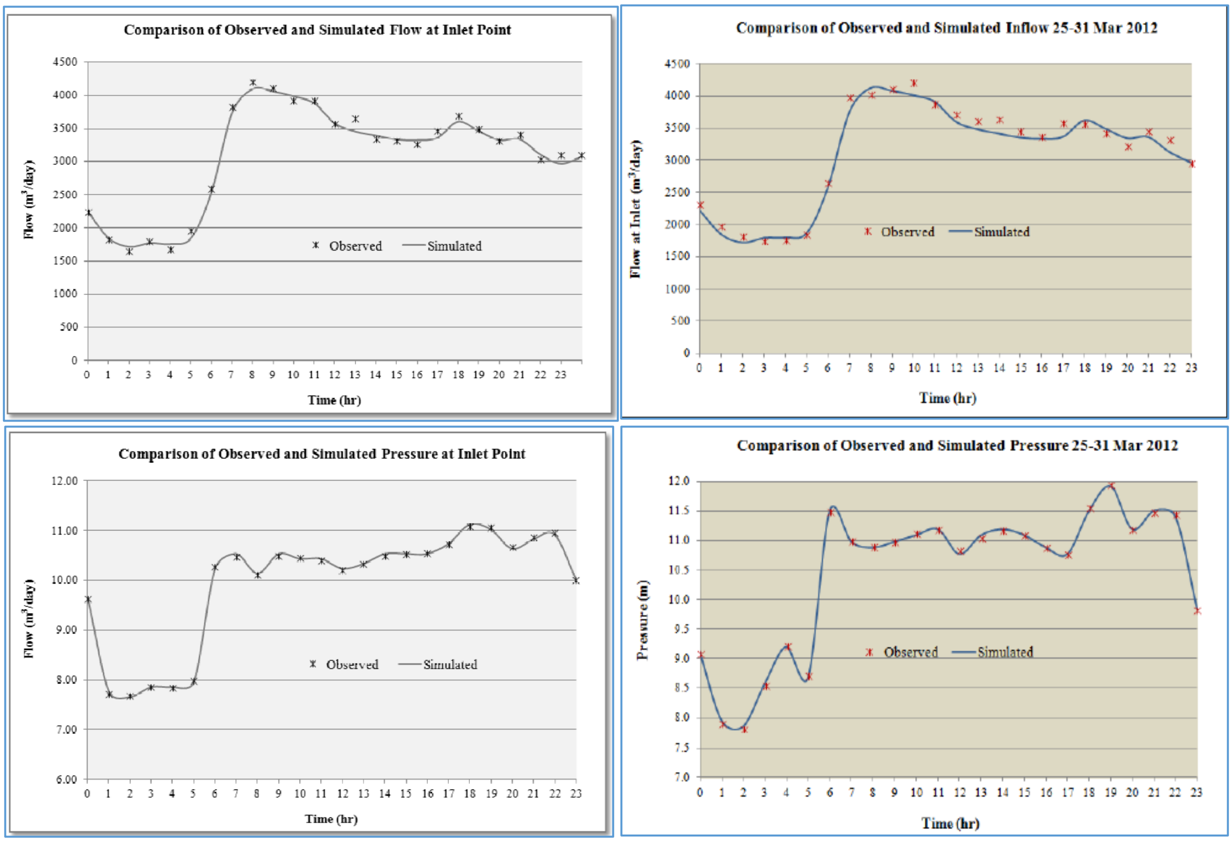

Figure 5: Network model calibration (top) and validation (bottom) trends for flow and pressure at inlet

(c) Water and energy conservation potential in MWA supply system: Table 6 presents the results of the modelling study carried out to explore the potential of conserving water (by reducing leakage losses), and energy through the various alternatives described earlier. It is apparent that alternatives A4 and A5 are incapable of fostering water conservation given that with these options the leakage losses actually increase due to increase in supply pressure.

Understandably, the leakage losses are minimal when the service pressure is low. Hence, for all alternatives the potential of water conservations is high when service pressures are low. However, reducing the base demand does not always result in lower leakage losses as seen in the results of A3.

Table 6: Water conserved in the alternatives analysed

Alternatives		Sub-Alternatives	Pressure (m)	Base Demand (%)	Water Conserved (m^3/day)	Energy conserved (kWh/day)
A0	Base case	A0	7.5	100		
A1	Pressure Management (Decreasing Service Pressure)	A1.1	3	100	224.3	40
		A1.2	5	100	110.9	20
		A1.3	6	100	63.0	11
		A1.4	7	100	18.6	3
A2	Demand Management (Decreasing Base Demand)	A2.1	7.5	90	-1.7	156
		A2.2	5	90	110.0	175
		A2.3	6	90	61.9	167
		A2.4	7	90	17.8	159
		A2.5	7.5	80	-3.3	316
		A2.6	5	80	109.2	336

		A2.7	6	80	61.2	327
		A2.8	7	80	17.1	320
A3	Energy Generated (Decreasing Service Pressure with Turbine Generator)	A3.1	5	100	100.6	18
		A3.2	6	100	72.4	13
		A3.3	7	100	26.5	5
		A3.4	5	90	104.8	175
		A3.5	6	90	76.2	169
		A3.6	7	90	26.3	161
		A3.7	5	80	109.0	336
		A3.8	6	80	80.2	331
		A3.9	7	80	25.2	321
A4	Pressure Management (Increasing Service Pressure)	A4.1	9	100	-38.6	5
		A4.2	12	100	-125.1	115
		A4.3	15	100	-226.7	173
		A4.4	18	100	-319.7	422
		A4.5	21	100	-403.0	370
A5	Pressure Management (Increasing Service Pressure with PRV)	A5.1	12	100	-102.0	119
		A5.2	15	100	-180.1	182
		A5.3	18	100	-250.0	435
		A5.4	21	100	-304.1	388

The energy conserved has two components— the total energy use at various stages of the MWA supply system, and energy used by consumers to pump water at household level due to low pressure supply. While the calculations for the former have been described earlier, the latter were found out through a filed survey, details of which are the subject of another upcoming article. The energy use at the consumers' end was calculated using Equation 1.

Pump Energy Consumption (kWh) = Pump Power (kW) x Operating Time (h) ………. [1]

Hence, the energy conserved for each alternative would be the total reduction in energy use when considering energy input both the utility (MWA) and the consumers, as shown in Table 6. The energy conservation has been calculated based on four cases: one real and three hypothetical. Case 1 corresponds to the actual field survey, while the remaining three cases have been developed to account for consumer bias/inaccuracies during the field survey.

In the present situation of 7.5m minimum service pressure, MWA consumes 0.1765kWh/m^3 while the consumers use 0.5kWh/m^3. The highest energy conservation occurs with alternative 2, service pressure of 5m with 80% base demand, which is capable of conserving 85,410kWh/year or approximately 224,630 Baht/year. The highest percentage of total energy consumption reduction (32%) in term of kWh/m^3 was found with alternative 4 and 5 with 18m service pressure. This includes increasing in energy use of MWA from 0.1765 to 0.216 kWh/m^3 and decreasing energy use of consumers from 0.28 to 0.245kWh/m^3.

5. CONCLUSION

The objective of this study was to evaluate alternatives to conserve water and energy in Thailand's largest water utility – Metropolitan Waterworks Authority (MWA) which supplies water almost 5 million m^3 of water per day to a population of more than 8 million through a network of 2 million customer connections. A thorough water and energy audit was carried out to understand the existing trends in use of these resources. The study revealed that approximately 4, 20, 41, and 35% of the total energy use per cubic meter of water input by MWA is used in raw water intake, water treatment, water transmission and water distribution respectively. A hydraulic model of a selected DMA was developed to test various alternatives of resource conservations. As expected, lower pressures and lower base demand can conserve more water due to the reduced leakage while the higher pressure would affect more leakage. More energy can be conserved if the service pressures by MWA are increased due to reduced use of energy by customers at household level. A reduction of 32% (from 0.68 to 0.46kWh/m^3) in energy consumption can be achieved with 18m of service pressure using PRV in the system. A detailed cost-benefit analysis and technical feasibility of the proposed alternatives are recommended for their application in the field. This study contributes in addressing the challenge of managing water and energy resources together and improves the understanding of water and energy nexus in municipal water supply systems.

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