Lowland Technology International 2018; 20 (2): 205-212
International Association of Lowland Technology (IALT): ISSN 1344-9656
Special Issue on: Green Technology for Sustainable Infrastructure Development

Research Paper

Raw water reserve and conveyance capacity of West Water Canal of Metropolitan Waterworks Authority

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ARTICLE INFORMATION

Article history:

Received: 03 January, 2017
Received in revised form: 21 May, 2017
Accepted: 21 July, 2017
Publish on: 07 September, 2018

Keywords:

Conveyance capacity
Hydrodynamics
MWA Raw water
West water canal of MWA

ABSTRACT

Metropolitan Waterworks Authority (MWA) is responsible for supplying potable water to Bangkok, Nonthaburi and Samut Prakan provinces. There are two raw water sources used, Chao Phraya River and Mae Klong River, conveyed via canal systems. At present, West Water Canal (WWC) system with the total length of 107 km carrying the discharge of about 20 m^3/s from Mae Klong River. It was designed to be capable to convey 45 m^3/s with using Bang Len Pumping Station (71 km from the upstream end). However, MWA modified the WWC system by constructing a bypass canal at the pumping station. Thus, water flows completely by the gravitation which saves both cost and energy. Nevertheless, it is expected that the present canal system cannot deliver water at its design conveyance capacity, and problems may arise in the future if water demand increases. In this study, we have performed a fully hydrodynamic one-dimensional model. It is found that the present maximum capacity is approximately 24 m^3/s. To meet the design capacity of 45 m^3/s without using the pumping station, it is necessary to implement 15-km canal modification and build an additional bypass canal. The redesign of the canal will help MWA to save the energy at least 4,750 Mwh/year. In addition, it should be known that how long and how much we can use water reserve in the canal for production if the inlet at Mae Klong River is temporally closed due to emergency or canal maintenance. From the model result, WWC system can reserve water for 15 and 12 hours for the cases of the existing system under 24 m^3/s and the modified system under 45 m^3/s, respectively.

1. Introduction

Metropolitan Waterworks Authority (MWA) uses surface water as a raw water supply from Chao Phraya River and Mae Klong River via canal systems. At present, it delivers approximately 5.2 million cubic meters per day. West water canal (WWC) system delivers about one-third amount of water from Mae Klong River. It will be more important because east water canal is almost at its full capacity and, thus, more water will be withdrawn and

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Note: Discussion on this paper is open until March 2019

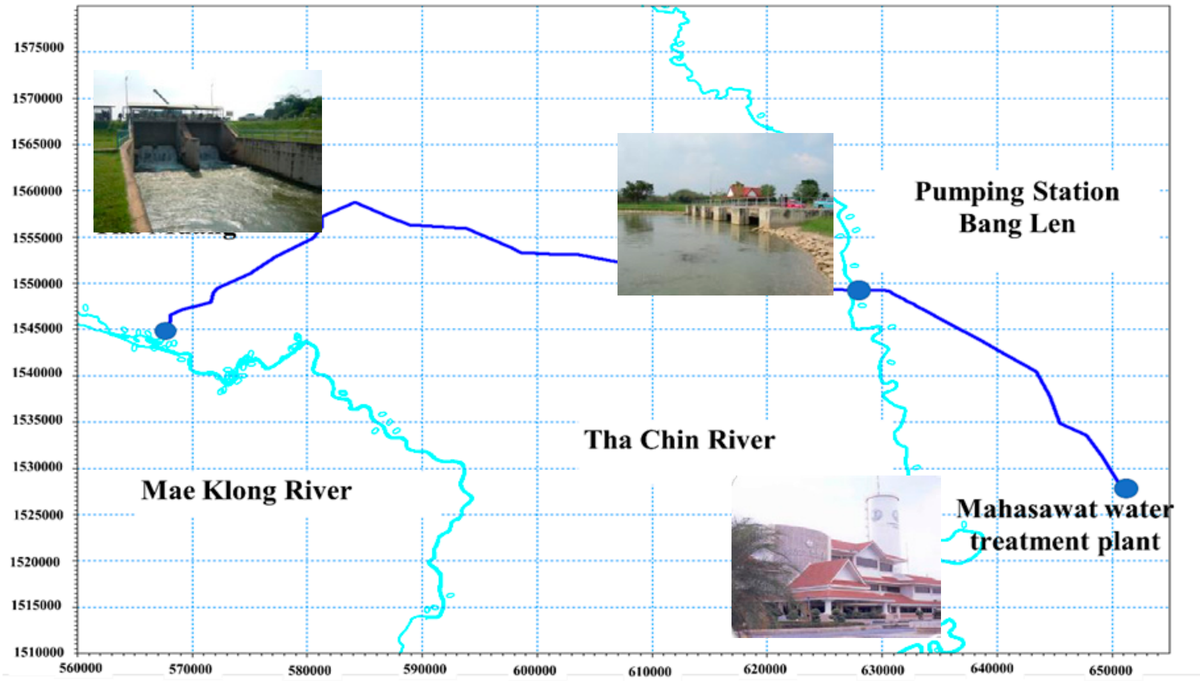

Fig. 1. West Water Canal Network where the upstream is at Tha Muang and the downstream is at Mahasawat WTP.

conveyed via WWC to meet an increase in water demand in the future. The WWC system was decided to be capable to convey 45 m^3/s with using Bang Len Pumping Station. However, MWA modified the WWC system by constructing a bypass canal at the pumping station. As a result, water delivered via the WWC system at present flows completely by the gravitation which saves both cost and energy. Nevertheless, it is expected that the canal system may not be able to deliver water at its design conveyance capacity, and problems may arise in the future if water demand increases to its maximum capacity. Since WWC has been operated 24 hours, there is a concern about the cases of emergency or maintenance that the inlet at Mae Klong River has to be temporally closed. How many hours can WWC shut down and reserve sufficient water for the operation of water treatment plant downstream without causing any adverse effects on the stability of WWC structure?

There are many examples of using the computer model to simulate flow problems for canal design and management (Malaterre and Baume,1997; Kim et al.,2016). To investigate raw water reserve and conveyance capacity of the WWC system, we have performed a fully hydrodynamic one-dimensional model and calibrated with the observed data from October, 2014 to January, 2016.

2. West Water Canal (WWC)

The construction of the west water canal system (WWC) can be divided into two phases. In the first phase

in 1997, raw water from Tha Chin River was taken at Bang Len Pumping Station and then pumped into the lower canal section of 35-km length and finally delivered to Mahasawat Water Treatment Plant (MH WTP) (TEAM Consult., 2002). Due to the expansion of urban and industrial areas in Tha Chin River Basin, raw water from Tha Chin River cannot meet an increasing demand and its quality becomes worse. As a result, MWA constructed the upper canal section of 71-km length and changed an inlet to Tha Muang to take water from Mae Klong River (**Fig. 1.**) (TEAM Consult., 2002; Progress Technology Consult., 2014) In addition, the pumping station have been cancelled since 2002 and water is delivered via a bypass canal.

The WWC system comprises of the earth-filled canals and the concrete-covered canals with various shapes and also many hydraulic structures such as gates, inverted siphons, culverts, flume, stop logs and trash racks (**Tables 1,2**). Due to limited space in some area, U-shape or concrete lining canal sections are used to reduce the cross-sectional area. In addition, water flume is used to cross a natural swamp. Otherwise, the earth-filled canal is used. When the canal has to pass roads or rivers, culverts and inverted siphons are installed, respectively. Stop logs are installed especially in the upper canal section to control at least 2-m water depth to protect the canal from bank failure.

Table 1. Cross-sections of West Water Canal

Upstream (km)	-	Downstream (km)	Section	Lining
0	-	3.669	U-shape	concrete
3.669	-	18.763	trapezoid	concrete
18.763	-	19.401	U-shape	concrete
19.401	-	38.497	trapezoid	concrete
38.497	-	39.547	U-shape	concrete
39.547	-	44.878	trapezoid	concrete
45.016	-	53.429	trapezoid	earth canal
53.429	-	53.884	flume	concrete
53.884	-	70.962	trapezoid	earth canal
70.962	-	106.84	trapezoid with berms	earth canal

Table 2. Hydraulic Structures in West Water Canal

Type	No. of Location
Gate	1
Culvert	25
Inverted Siphon	22
Stop log	27

3. Model setup and calibration

3.1 Model setup

In this study, MIKE11 computer software by DHI (DHI., 2009) is applied to WWC system to solve one-dimensional hydrodynamic problems. The software uses the shallow water equations as follows:

Continuity equation:

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \quad [1]$$

Momentum equation in the streamwise direction:

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{\alpha Q^2}{A}\right)+gA\frac{\partial h}{\partial x}+\frac{gn^2Q|Q|}{AR^{4/3}}=0 \quad [2]$$

where Q is flow discharge, A is flow area, q is lateral inflow, x is streamwise direction, t is time, h is water level above datum, n is Manning coefficient, R is hydraulic radius, α is momentum distribution coefficient and g is gravitational acceleration.

The model input is comprised of canal cross-sections (**Table 1**) and hydraulic structures (**Table 2**) and boundary conditions (inflow at Tha Muang inlet, water level at MH WTP, side flows at 3 locations along the canal and water losses of about 3%).

For flow behaviors at culverts and inverted siphons, we used the energy loss equation as follows:

$$h_L=\frac{KQ^2}{2gA^2} \quad [3]$$

where h_L is energy loss and K is energy loss coefficient.

For flow behaviors at stop logs, we considered them as weirs and used Honma formula. The formula separates the flow characteristics into two stages, free and submerged overflows, such that

Use the free overflow equation when $(H_{ds}-H_w)/H_{us}< 2/3$:

$$Q=C_1W(H_{us}-H_w)\sqrt{(H_{us}-H_w)} \quad [4]$$

Use the submerged overflow equation when $(H_{ds}-H_w)/H_{us}> 2/3$:

$$Q=C_2W(H_{ds}-H_w)\sqrt{(H_{us}-H_{ds})} \quad [5]$$

where H_w is weir level, H_{us} and H_{ds} are water levels upstream and downstream of weir, respectively, W is weir width, and C_1 and C_2 are discharge coefficients where

$$C_2=(3/2)\sqrt{3}C_1 \quad [6]$$

3.2 Model calibration and verification

Manning coefficient (n) and energy coefficient (K) are used as calibration parameters. The observed data between October, 2014 and January, 2016 have been used for the calibration and verification. There are two types of the data, automatic and manual types. However, there are some missing or errors data. Thus, we used the data that are valid.

3.2.1 Water discharge

The comparison between the observed and simulated discharges at the downstream end (MH WTP) is shown in **Fig. 2**. It is found that the maximum discharge is about 20 m^3/s. A good agreement between them can be found with RMSE of 1.24 m^3/s and R^2 of 0.67. The high discrepancy between them happening at some period is due to that the daily observed water levels using as a downstream boundary condition rapidly fluctuated. For example, during September 8-27, 2015, the water level increased from 1.02 m MSL to 1.61 m MSL and then decreased to 1.06 m MSL.

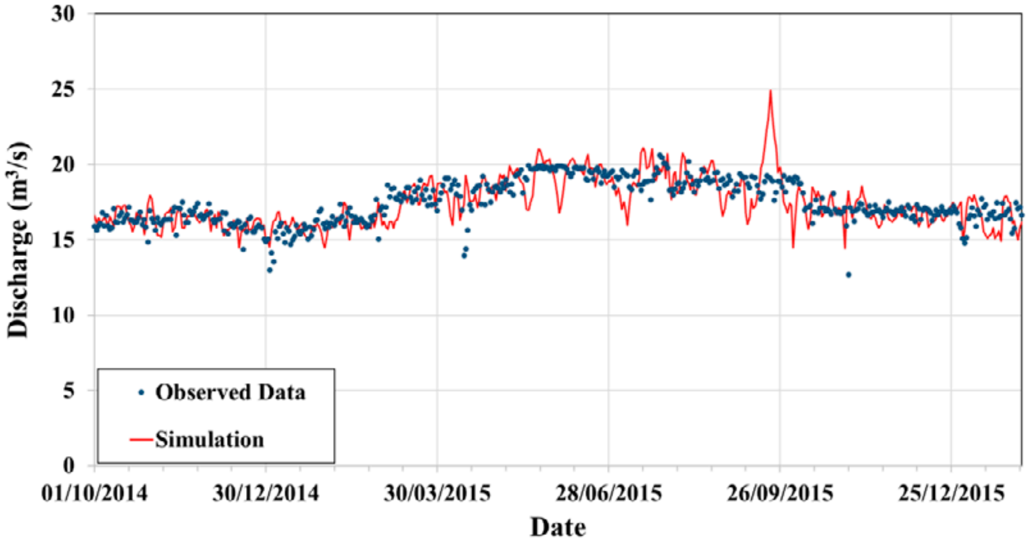

Fig. 2. Discharge at Mahasawat Water Treatment Plant between observed data and simulated results.

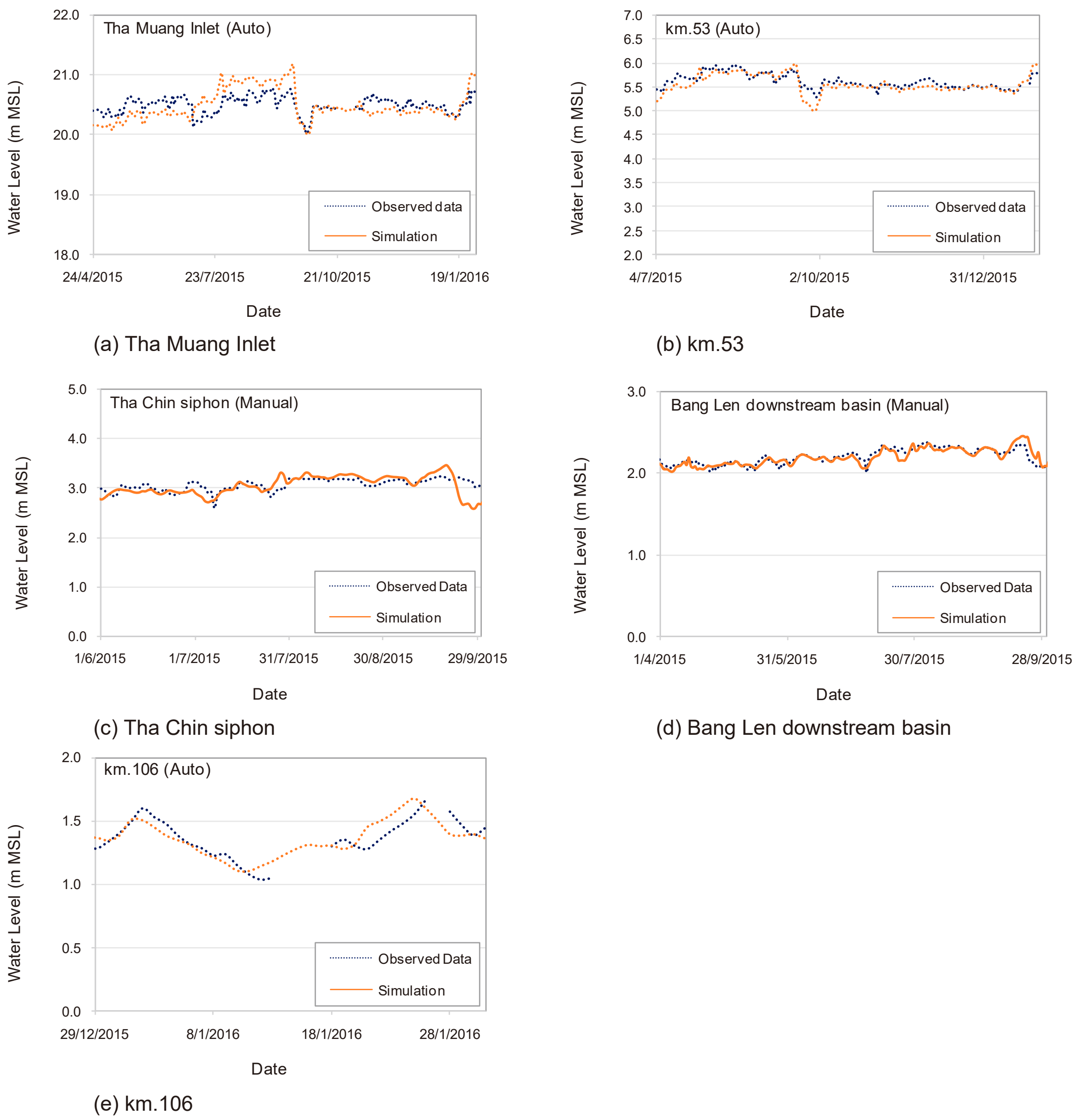

Fig. 3. Model calibration of water surface elevation.

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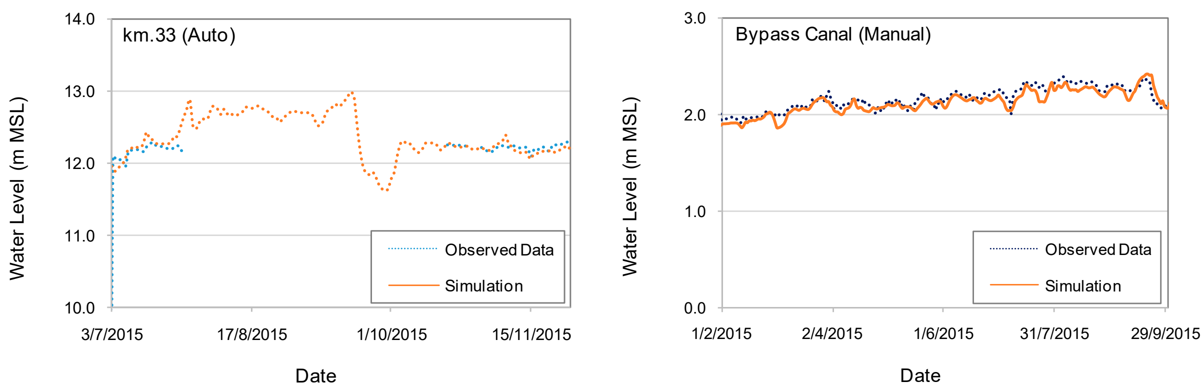

(a) km.33 (b) Bypass Canal

Fig. 4. Model verification of water surface elevation.

Table 3. Statistic Results of Water Surface Elevation at Monitoring stations.

	Record type	Location	RMSE (m)	R^2	period
Calibration	Auto	Tha Muang Inlet	0.214	0.582	24/4/2015 - 21/10/2015, 4/11/2015 - 31/1/2016
	Auto	km.53	0.069	0.535	4/7/2015 - 26/10/2015, 30/10/2015 - 22/1/2016, 26/1/2016 - 31/1/2016
	Manual	Tha Chin siphon	0.160	0.570	1/6/2015 - 30/9/2015
	Manual	Bang Len downstream basin	0.046	0.906	1/3/2015 - 30/9/2015
	Auto	km.106	0.089	0.830	29/12/2015 - 13/1/2016, 19/1/2015 - 26/1/2015, 28/1/2015 - 31/1/2015
Verification	Auto	km.33	0.105	0.542	3/7/2015 - 26/7/2015, 19/10/2015 - 26/10/2015, 30/10/2015 - 27/11/2015
	Manual	bypass canal	0.059	0.918	1/2/2015 – 30/9/2015

3.2.2 Water surface elevation

Data from five monitoring stations were used for the calibration, and two stations were for the verification. **Figure 3** shows five time series graphs for the calibration from (a) the most upstream end at the Tha Muang Inlet to (e) the station km.106 from the upstream. While the word “Auto” in the graphs means the automatically-observed data, “Manual” is the manually-observed data. At the Tha Muang Inlet, the water level fluctuated between 20 and 21 m MSL. Since the upper canal section (km.0 to km.71) has a steep bed slope, the water level dropped greatly as the water level at the Tha Chin siphon (the end of the upper canal section) was approximately 3 m MSL, Thus, the water level difference was around 17-18 m. The Bang Len downstream basin is the start of the lower canal section (km.72), and the km.106 station is about 1 km upstream from the downstream end. It is found that the water level difference was only 0.5-1 m. Thus, the canal cross-sections of the lower canal section are much larger than the ones of the upper canal section. In **Fig. 4**, two time series graphs show the comparison between the observed water level and the simulated one at (a) the km.33 station and (b) the station at the bypass canal connecting between the upper and lower canal sections. **Table 3** shows the statistic results of both calibration and verification of our model. It is found that the automatically-observed data have a lot of missing data. However, the good agreement can be found with RMSE of 0.046-0.214 m and R^2 of 0.535-0.918. Thus, our model

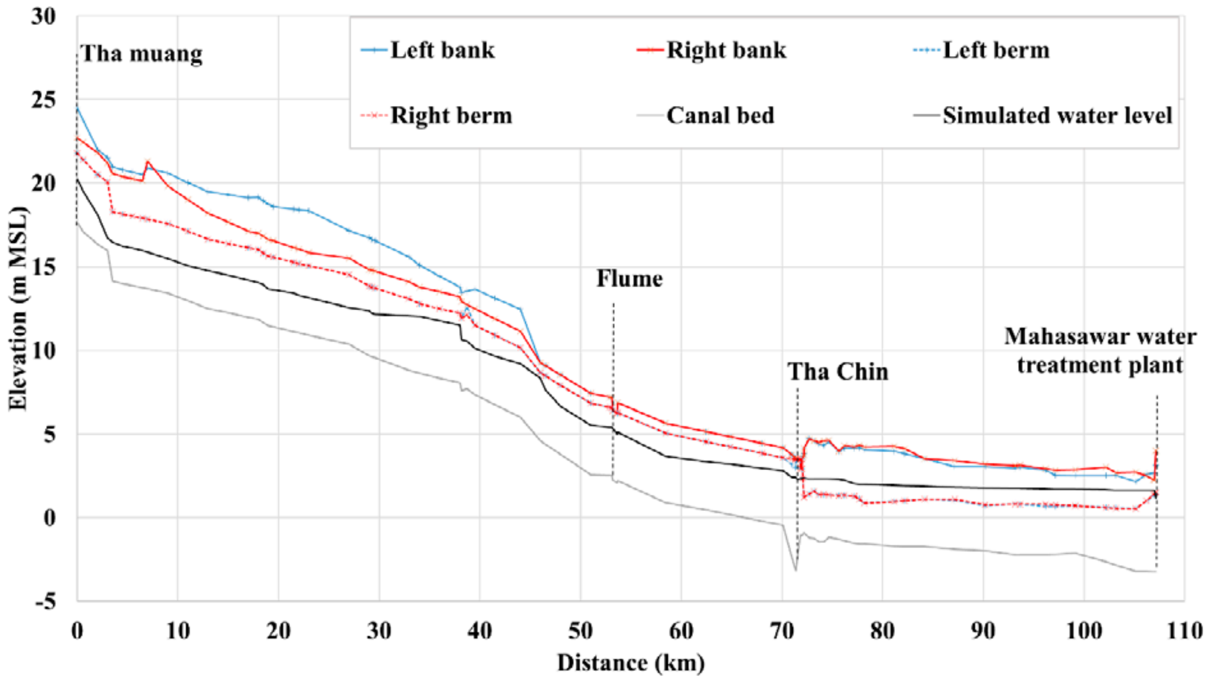

Fig. 5. Water elevation profile of the existing canal condition, where Q_{max} = 24 m^3/s.

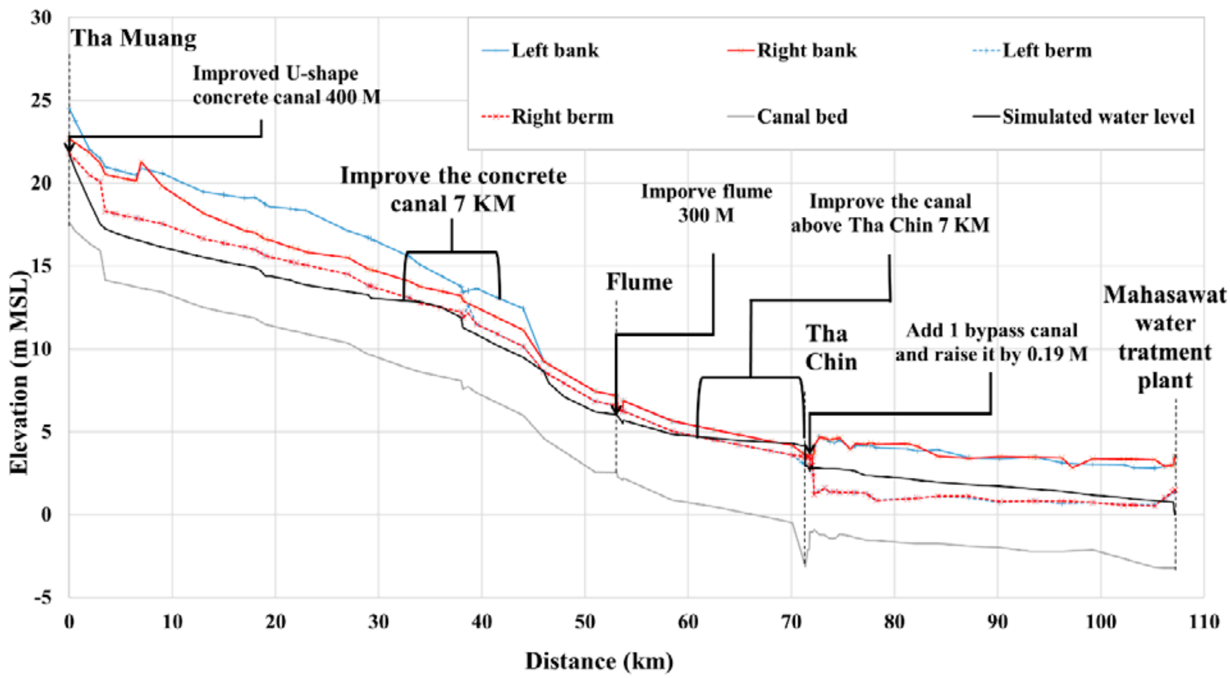

Fig. 6. Water elevation profile and locations of the canal modification and the, where Q_{max} = 45 m^3/s.

can simulate the present situation of the WWC system satisfactorily, and it is ready to be used for our study.

4. Results and discussion

4.1 Conveyance capacity

The following conditions are applied in the simulation to find the conveyance capacity:

1) Free-board equals to 0.50 m

2) The maximum water level for U-shape and concrete lining sections is top of the concrete crest minus the free board.

3) The maximum water level for Earth lining sections is bank level minus the free board.

4) The maximum allowable velocities for concrete and earth lining sections are 5.49 m/s (USDA.,2007) and 0.92 m/s (Resource Engineering Consult., 2000), respectively.

The first scenario is to find the maximum conveyance capacity (Q_{max}) for the existing canal condition, where stop logs are installed and downstream water level equals to 1.15 m MSL (the average value). It is found that Q_{max} = 24 m^3/s. **Figure 5** shows water elevation profiles for the existing canal condition, where Q_{max} = 24 m^3/s. It is found that water level is close to the free board limitation at bypass canal and km.105 from the inlet. According to the operation manual (TEAM Consult., 2002), the Bang Len pumping station was designed to pump water with pump head (H_p) of approximately 1 m. With the use of bypass canal instead, MWA will save the energy ($\rho g Q_{max} H_p$) of at least 2,500 Mwh/year (assumed pump efficiency of 80% (White, 2005)). This large energy saving implies that MWA should consider the option to continue delivering water by gravity by modifying the canal to increase Q_{max}.

For the second scenario, we consider the canal modification to meet the maximum allowance discharge of 45 m^3/s, of which the Royal Thai Irrigation Department has agreed to support MWA. In addition, the downstream water level is set to be +0.00 m MSL according to the design criteria (Resource Engineering Consult., 2000). **Figure 6** shows water elevation profile and locations for the canal modification, where Q_{max} increases to 45 m^3/s. It is necessary to improve the canal cross-sections by raising their berms and banks for about 15 km in the upper canal section and add one more bypass canal with the same shape. With the modification, MWA will save the energy of at least 4,750 Mwh/year in the future. In addition, the maintenance and operational costs of canal modification are significantly lower than that of the pumping station.

4.2 Water reserve

The scenario for the cases of emergency or maintenance that the inlet at Mae Klong River has to be temporally closed is analyzed in this section. In the operation and maintenance manual (TEAM Consult., 2002), it is written that water depths in the earth lining cross-sections of the upper and lower canal sections should be at least 2 and 3 m, respectively. It is assumed that the concrete cross-sections should not have any severe adverse effects for the intermittent stop. This criterion is used in this study. Nevertheless, the slope stability analysis from the new report (Progress Technology Consult., 2014) shows that water depth can be as low as 1 m in the lower canal section without causing the damage.

Table 4 shows two scenarios for water reservation that corresponds to the previous two scenarios of conveyance capacity. Water reserve times are 15 and 12 hrs for the existing canal condition and canal modification, respectively. From the results, there is no water in the concrete cross-sections near the inlet, and the critical condition of 2 m water depth happens at the earth lining cross-sections at km.45-71 in the upper canal section. It is also found that water reserve time is not linearly related to the discharge because, for a higher discharge, there is more volume of water reserve within the canal.

Table 4. Water reserve times for the discharges of 24 and 45 m^3/s

Scenario	Discharge (m^3/s)	Water reserve time (hr)
Existing canal	24	15
Canal modification	45	12

5. Conclusions

We have investigated the raw water conveyance capacity and water reserve of West Water Canal of Metropolitan Waterworks Authority by the one-dimensional simulation flow model. Due to the change from using a pump to gravitational flow via the bypass, the maximum discharge of the existing canal system is found to be 24 m^3/s. However, at present situation, MWA can save the energy of at least 2,500 Mwh/year. To raise the capacity to its original design value of 45 m^3/s, MWA has to build one more bypass canal and modified canal sections by raising berms and banks for about 15 km. Then, MWA will save the energy of at least 4,750 Mwh/year in the future. For the emergency case, water reserve times are 15 and 12 hrs for the discharges of 24 and 45 m^3/s. The time is not a linear function of the discharge because more reserve water is within the canal as more discharge is applied. In conclusion, the flow model is proved to be a beneficial decision support tool for water management.

Acknowledgements

This study is funded by Metropolitan Waterworks Authority.

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