KKU ENGINEERING JOURNAL 2016;43(S3):454-458 Research Article

KKU Engineering Journal

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Effect of elevation to accuracy in water pipeline network simulation

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Received April 2016
Accepted June 2016

Abstract

EPANET is hydraulic (pressure and flow) and water quality behavior (chlorine disinfectant) simulation software, developed by Lewis A. Rossman United States Environmental Protection Agency (EPA). Using "Gradient Method" as defined by Todini and Pilati (1987) to solve the flow continuity and head loss equation. It is kind of open-source, which can be developed further. Therefore, Metropolitan Waterworks Authority (MWA) of Thailand would like to use this software for pressure management of main pipeline network. MWA's service area covers over 3 provinces; Bangkok, Nonthaburi, and Samut Prakarn. Each area has a different elevation. Recently, the pipe network model has used only two horizontal coordinates while without vertical coordinate or elevation. Thus, the error from model computation is still high. In this study the elevation of pumping station is changed using as-built drawing data that reference from Mean Sea Level (MSL). The elevation has been changed using estimation as each road surface level from Royal Thai Survey Department's map. The improved model has accuracy about 88.76% higher than the existing model, about 17.92 %. Eventually this study is to show how important the elevation is in EPANET model.

Keywords: Hydraulics simulation, EPANET, Water distribution network, Pipeline network model

1. Introduction

EPANET is hydraulic (pressure and flow) and water quality behavior (chlorine disinfectant) simulation software developed by Lewis A. Rossman United States Environmental Protection Agency (EPA). It is open source, which can be developed further in many applications. EPANET was utilized in the water distribution system design and water pressure management. MWA's pipe network is large and sophisticated as shown in Figure 1. Network consists of 13,738 pipes and 18 pumping stations. Estimation of water behavior at different times of the day, it is difficult to calculate. For this reason, MWA has used EPANET as decision tool in water supply planning. MWA plans to integrate SCADA (Supervisory Control and Data Acquisition) into water supply and water management system. The aim of this study is to develop EPANET from current version that working under Windows/Linux [1] to enable networking function and working under other operation systems with better accuracy.

2. The basic equation of pipeline hydraulics system

2.1 Conservation of mass (continuity) [2]

$$Q = \int_A v dA = V_1 A_1 = V_2 A_2 \qquad (1)$$

Where Q =flow rate (volume/time)
V =mean velocity (length/time)
A =cross-section area (square length)

2.2 Conservation of energy (Bernoulli Equation)

$$\frac{p_i}{\gamma} + \frac{V_i^2}{2g} + z_i = \frac{p_j}{\gamma} + \frac{V_j^2}{2g} + z_j + h_f \qquad (2)$$

Where $\frac{V^2}{2g}$ = Velocity head or kinetic energy (length)
$\frac{p}{\gamma}$ = Pressure head or flow work or pressure energy (length)
z = Elevation head or potential energy (length)
h_f = Head loss (length)
p = pressure (force/area)
z = Elevation (length)
g = acceeration (length/time^2)
i, j = index number (1...n)

The pipe has same diameter, flow rate, and velocity ($Q_i = Q_j, V_i = V_j$) So Equation (2) is

$$\frac{p_i}{\gamma} + z_i = \frac{p_j}{\gamma} + z_j + h_f \qquad (3)$$

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doi: 10.14456/kkuenj.2016.154

The $\frac{p}{\gamma}$ is Static Head or Pressure Head [3],

and $\frac{p}{\gamma}+z=H$ is Head Grade Line [3]

$$\frac{p_i}{\gamma}+z_i-\frac{p_j}{\gamma}+z_j=h_f \tag{4}$$

$$H_i-H_j=h_f=R_kQ_k^n \tag{5}$$

Where Q = volume flow rate (volume/time)

H = nodal head (length)

Figure 1 MWA main pipeline network

2.3 Head loss

Hazen-Williams formula is the most commonly used head loss formula. It cannot be used in liquid other than water and was originally developed for turbulent flow only [4].

Darcy-Weisbach formula is the most theoretically correct depending on friction parameter [4].

The Chezy-Maning formula is more commonly used for open channel flow [4].

2.4 EPANET

EPANET uses "Gradient Method" (Todini and Pilati (1987)) to solve the flow continuity and head loss equations that characterize the hydraulic state of the pipe network [5]. In matrix form the problem can be formulated as follows [6]:

$$\begin{bmatrix}\mathbf{A}11 & \mathbf{A}12\\ \mathbf{A}21 & \mathbf{0}\end{bmatrix}\begin{bmatrix}\mathbf{Q}\\ \mathbf{H}\end{bmatrix}=\begin{bmatrix}\mathbf{A}10\ \mathbf{H}0\\ \mathbf{q}\end{bmatrix} \tag{6}$$

Where $\mathbf{A}12=\mathbf{A}21^T$ (np,nn) unknow head nodes incidence matrix

$\mathbf{A}10=\mathbf{A}01^{\mathrm{T}}$ (np,no) fixed head nodes incidence matrix

$\mathbf{Q}^{\mathrm{T}}=\left[Q_1,Q_2,\ldots,Q_{np}\right]$ (1,np) flow rates in each pipe

$\mathbf{q}^{\mathrm{T}}=\left[q_1,q_2,\ldots,q_{nn}\right]$ (1,nn) nodal demands

$\mathbf{H}^{\mathrm{T}}=\left[H_1,H_2,\ldots,H_{nn}\right]$ (1,nn) unknown nodal heads

$\mathbf{H}0^{\mathrm{T}}=\left[H0_1,H0_1,\ldots,H0_{no}\right]$ (1,no) fixed nodal heads

$$\mathbf{A}11=\begin{bmatrix}R_1\left|Q_1\right|^{n_1-1} & & & \\ & R_2\left|Q_2\right|^{n_2-1} & & \\ & & \ddots & \\ & & & R_{np}\left|Q_{np}\right|^{n_{np}-1}\end{bmatrix} \tag{7}$$

Is an (np,np) diagonal matrix

With

nn = number of node with unknown head

no = number of node with fixed head

np = number of pipe with unknown flow

$$\mathbf{A}12(i,j)=\begin{cases}1 & \text{if flow of pipe } i \text{ enters to node } j\\ 0 & \text{if pipe } i \text{ and node } j \text{ are not connected}\\ -1 & \text{if flow of pipe } i \text{ leaves to node } j\end{cases} \tag{8}$$

$$\begin{bmatrix}\mathbf{A}11 & \mathbf{A}12\\ \mathbf{A}21 & \mathbf{0}\end{bmatrix}\begin{bmatrix}\mathbf{Q}\\ \mathbf{H}\end{bmatrix}-\begin{bmatrix}\mathbf{A}10\ \mathbf{H}0\\ \mathbf{q}\end{bmatrix}=\left[\mathbf{F}\right] \tag{9}$$

Applying the Newton-Raphson iteration technique to solves this equation system.

2.5 Newton –Raphson [7]

$$f(x)\cong f(x_0)+(x-x_0)f'(x_0)=0 \tag{10}$$

$$f(x_0)+(x-x_0)f'(x_0)=0$$

$$(x-x_0)f'(x_0)=-f(x_0);\quad f'(x_0)=\text{ Slope}$$

$$f'(x_0)\Delta x=-f(x_0);\qquad (x-x_0)=\Delta x$$

$$\Delta x=\frac{-f(x_0)}{f'(x_0)}$$

$$\Delta x=-f'(x_0)^{-1}f(x_0)$$

$$\{\Delta\mathbf{x}\}=-\{\mathbf{F}'\}^{-1}\{\mathbf{F}\}\ ;\ \{\mathbf{F}'\}=\mathbf{J}\text{ (Jacobian matrix)}$$

$$\{\Delta\mathbf{x}\}=-\mathbf{J}^{-1}\{\mathbf{F}\} \tag{11}$$

Updating $\{\mathbf{x}\}$ next iteration following;

$\{\mathbf{x}\}=\{\mathbf{x_0}\}+\alpha\{\Delta\mathbf{x}\}$; α is Relaxation Factor (12)

Term of vector matric $\mathbf{H}$ and $\mathrm{H}0$ in equation (9) are head grade line were defined in equation (4). Current model use only static head ($\frac{p}{\gamma}$) for calculation, not include elevation head (z). So, there is computing error in current model.

3. Materials and methods

The study found that current models are also required to correct the error in term of accuracy. It was found that MWA's main pipeline network is only two – coordinate without elevation. Each node in the network has been defined with same elevation (0 for all nodes). In fact each nodal elevation is not on the same level varying on the elevation of each ground surface. Therefore the error from inaccurate elevation will strongly affect the water pressure in each area. The current heads used in most calculations are all static head, but EPANET requires head grade line (static head + elevation) for computation as shown in equation (4). Therefore, it is necessary to correct various nodal elevations. Especially, all nodes (fixed head node) at the pumping station are required.

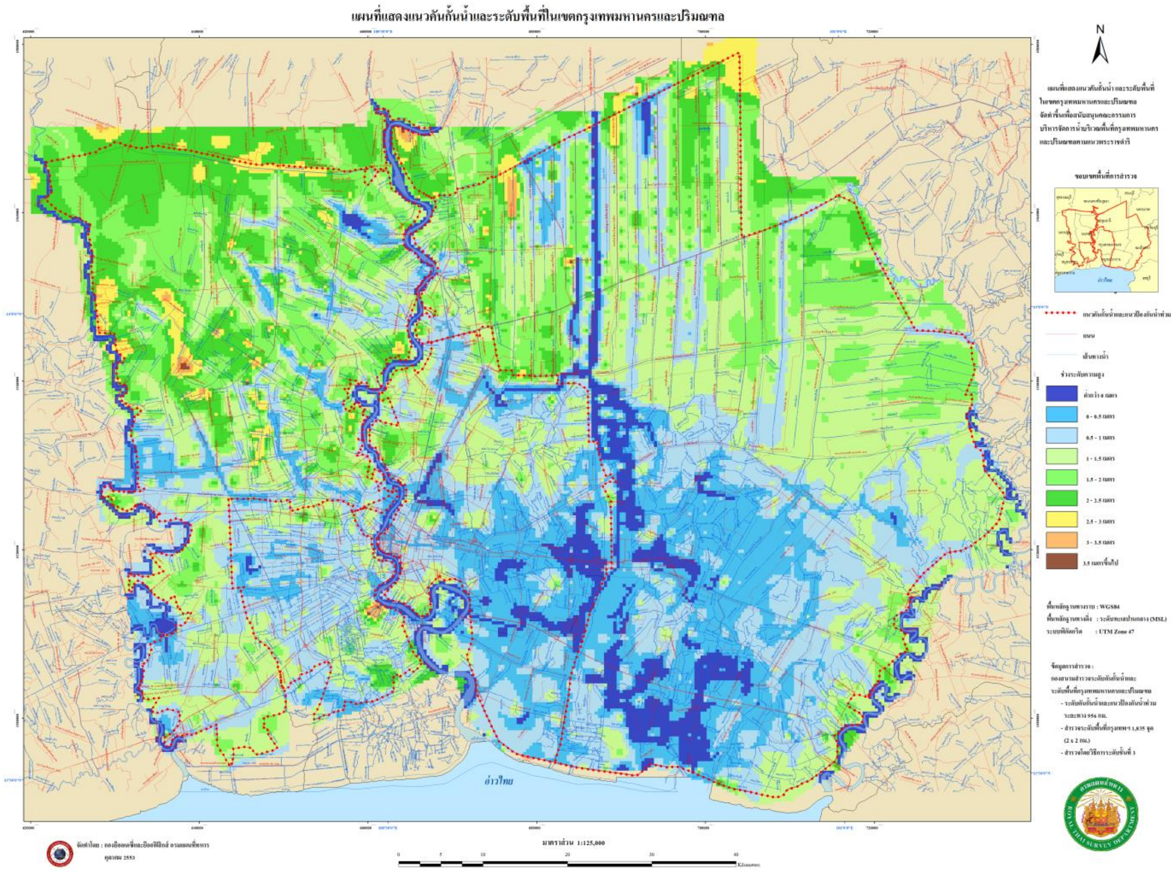


Figure 2 Royal Thai survey department's map

Commonly in Bangkok area, the elevation from construction project use WGS-84 (World Geodetic System of 1984) data system instead of mean sea level (MSL.) in order to avoid minus value (0 meter MSL = 35.03 meter WGS-84). Generally water pressure calculation refers from MSL. Therefore, we have conversed data from WGS-84 to MSL. We have only elevation data at an as-built drawing of pumping station only. In pipeline we do not have any elevation data. Pumping station elevation can be corrected as Table 1.

Table 1 Pumping Stations Elevation

No.	Pumping station	Elevation (MSL.)
1	Phetkasem	-0.549
2	Bang Phli	-0.63
3	Rat Burana	0.07
4	Ladkrabang	0.07
5	Lumphini	-5.43
6	Khlong Toe	0.07
7	Tha Phra	0.07
8	Bang Khen 1	0.07
9	Bang Khen 2	0.07
10	Phahonyothin	0.07
11	Lat Phrao	0.07
12	Samrong	0.07
13	Min Buri	0.07
14	Samsen 4	0.07
15	Samsen 3	0.07
16	Samsen 2	0.07
17	Thon Buri	0.07
18	Mahasawat	0.07

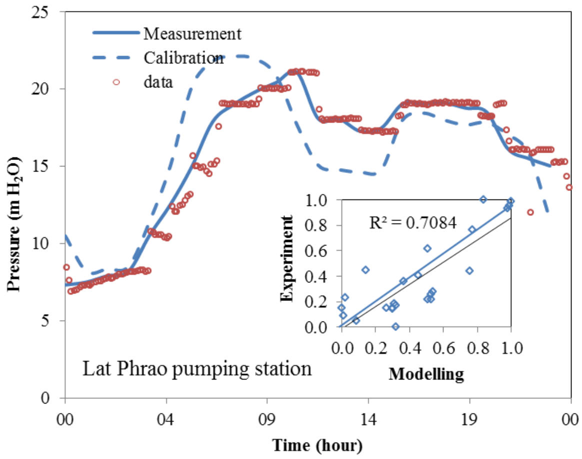
This study found that most of pumping station is 0.07 meter above mean sea level. However in case of Lumphini pumping station has 5.43 meter below mean sea level thus it necessary to correct head by compensate elevation. Highlight dates in Table 1 is not a true data while data as most of pumping station elevation are assumed.

In the nodal elevations of the pipe were corrected using an estimate of road surface of each area. The road surface dates of each area in Bangkok metropolitan region from Royal Thai survey department's map is used as shown in Figure 2. So the elevation of each node in pipeline is assumed to be equal to road surface.

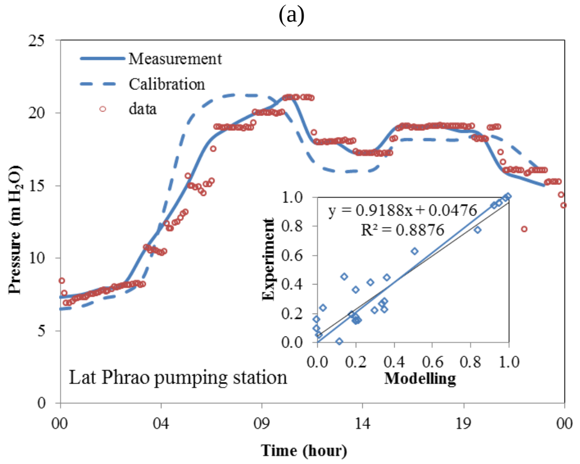
In this modified model, the calibration data and measuring data of water distribution system (WDS) are corrected. Comparing data of previous model and new model in R-squared value is shown in Figure 3(a) and 3(b). R-squared is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determinations for multiple regressions. In general, the higher the R-squared, the better the model fits data. For example, in case of high pressure pumping station such as Lat Phrao's pumping station accuracy increased from 70.84 % to 88.76 %. In other pumping stations after corrected we found accuracy levels up to 80 % as shown in Figures 4 and 5.

4. Conclusion

This study is to show that there is necessary to assign elevation to each node in main pipeline as found results. New pipeline network model has better accuracy than previous model. Wherever nodal elevations are estimated from a road surface. In fact, the pipeline elevations are not equal to the road surface. So the actual elevation to each node should be used in order to have better accuracy. Further study should be enabling networking function for working with SCADA system and account a leaks in pipeline and graphics interface. While the results are still limited in this excel file. It can be plotted as pressure map at different time as shown in Figures 6 and 7.



(a)



(b)

Figure 3 Simulation result of Lat Phrao pumping station (a) old model (b) new model

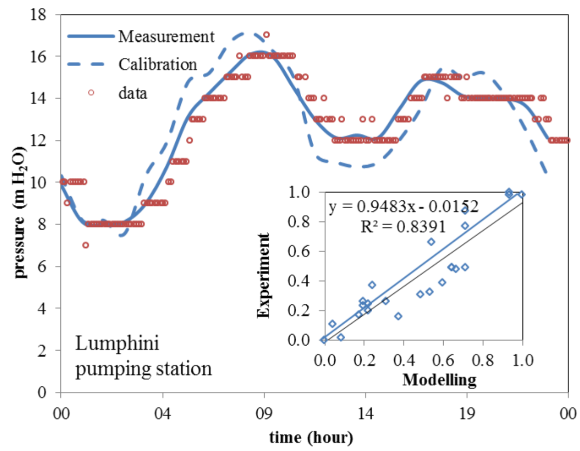


Figure 4 Simulation results of Lumphini pumping station

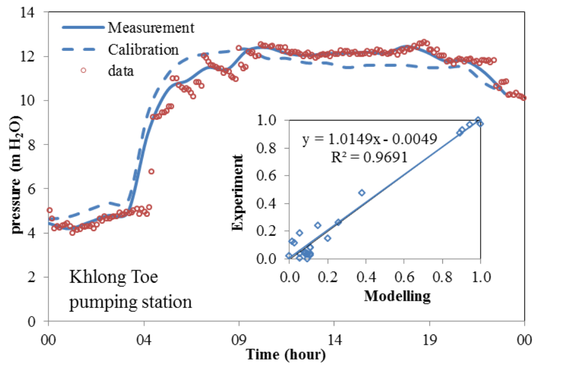


Figure 5 Simulation results of Khlong Toe pumping station

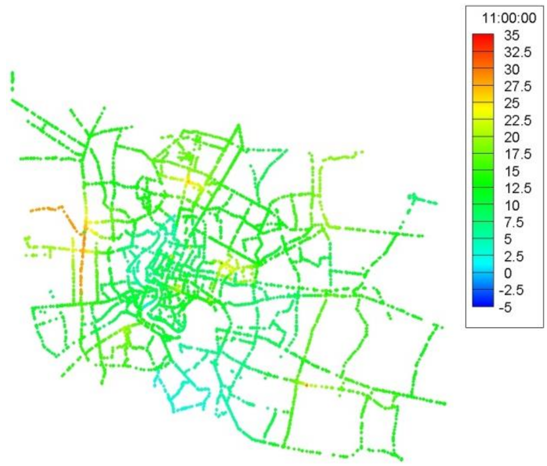


Figure 6 Pressure map at 11 A.M.

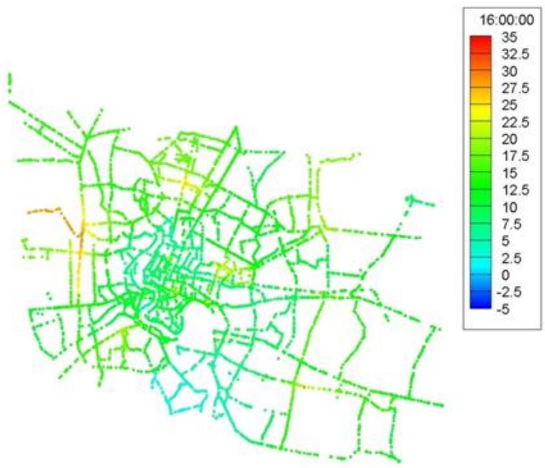


Figure 7 Pressure map at 4 P.M.

5. Acknowledgment

The authors would like acknowledge Metropolitan Waterworks Authority (MWA) Thailand for supporting important dates to this study.

6. References

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