

# Elevation Effect in Urban Water Distribution Model

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**Abstract.** Metropolitan Waterworks Authority (MWA) is Thailand's national government agency responsible for the supply of water to 3 provinces Bangkok, Nonthaburi and Samut Prakan with more than 2,384.9 km<sup>2</sup> of service area and 2,281,058 consumers in the year 2016. Bangkok, which is both the capital and the economic center of the country, is densely populated. Consequently, there is a huge demand for water; MWA has to supply 5.914 million cubic meters of water per day. Because the metropolitan water supply area is a densely populated city, the water supply system is very complex like a spider's web. For this reason, MWA has adopted EPANET software for its water supply managing tool in the main pipeline system. There are some mistakes in the main pipe network; the elevations of the nodes are not assigned, so there are some errors. In this study, we have assigned elevations for all nodes on the pipeline network based on mean sea level (MSL). After adjusting the elevation of each node, it was found that the new pipeline network has increased the correlation between means to 0.893 from the existing model mean of that is 0.803 of accuracy up 0.09 (11.2%).

## 1 Introduction

Metropolitan Waterworks Authority (MWA) is Thailand's national government agency responsible for the supply of water to 3 provinces Bangkok, Nonthaburi and Samut Prakan. These 3 provinces are heavily populated. Bangkok is the capital and economic centre of Thailand, Samut Prakan is an industrial city and Nonthaburi is a growing city. There are many different types of customers, residential and public water subscribers, such as hotels, schools, factories, restaurants, cafes, bars, shopping malls, offices, parks, temples and residential houses of different types (duplex or multiplex villas with garden, apartment flats etc.) in the MWA service area. Therefore, MWA service area has high water consumption. Each day, MWA is required to supply 5.914 million m<sup>3</sup> water to the service area.

The water supply system of MWA is based on 2 main water sources (Chao Phraya River and Mae Klong River), 4 Water Treatment Plants and 18 pumping stations. The MWA plans to supply enough water to meet the needs of consumers with a minimum water pressure of 10 meters head for all service area.

Practically, it is unreasonable to expect to ensure the availability of sufficient quantity and pressure of good quality water to the various sections of the community in accordance with the demand 100% of the true. Many computer tools have been developed; out of all the tools available EPANET has become the most popular and convenient for the effective design of complex pipe networks [1]. EPANET is a decision tool to manage the

water distribution system to meet the needs of the consumer at all times of day with proper water pressure. Water distribution system, however is related to production cost and water pumping energy.

## 2 MWA Main Pipeline Network

MWA main pipeline network is large and very complex containing 1,727.088 kilometres of pipes with diameters ranging between 500 mm and 1800 mm, which are supplied by 4 treatment plants and 18 pumping stations. All pumping stations are equipped with variable speed drive pumps. MWA has divided the service area to 5 zones, 18 branches and 669 District Metered Areas (DMAs). MWA main piping network consists of pipes, reservoirs, pumps and pressure reducing valves (PRV), etc. The piping elements are connected like a spider's web (Figure 1). Computation of flows and pressures in a complex network has been a great challenge and of interest for those involved with designs, construction and maintenance of public water distribution systems [1]. As a result, MWA has adopted EPANET software to help manage the main pipeline system. EPANET is a hydraulic (pressure and flow) and water quality behaviour (chlorine disinfectant) simulation software, developed by Lewis A. Rossman of 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 [2]. It is open source, so can be developed further.

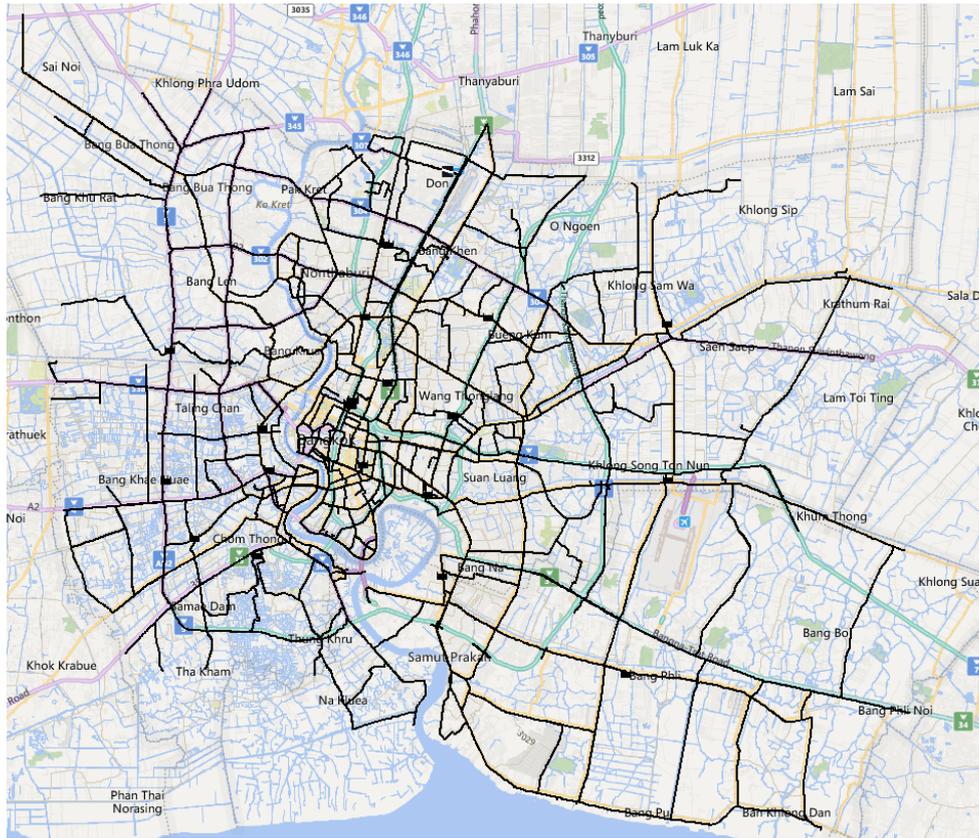


Figure 1. MWA main piping network.

### 3 The basic equation of pipeline hydraulics system

#### 3.1 Conservation of mass (continuity) [3]

$$Q = V_i A_i = V_j A_j \quad (1)$$

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

#### 3.2 Conservation of energy (Bernoulli Equation)

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

where  $\frac{V^2}{2g}$  = Velocity head (length)

$\frac{p}{\gamma}$  = Pressure head (length)

$z$  = Elevation head or potential energy (length)

$h_f$  = Head loss (length)

$p$  = pressure (force/area)

$g$  = acceleration (length/time<sup>2</sup>)

$i, j$  = index number (1...n)

In pipes of the same diameter, if both flow rate and velocity are the same ( $Q_i=Q_j$ ,  $V_i=V_j$ ). Equation (2) becomes.

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

$\frac{p}{\gamma}$  is Static Head or Pressure Head and  $\frac{p}{\gamma} + z = H$  is Head Grade Line [4].

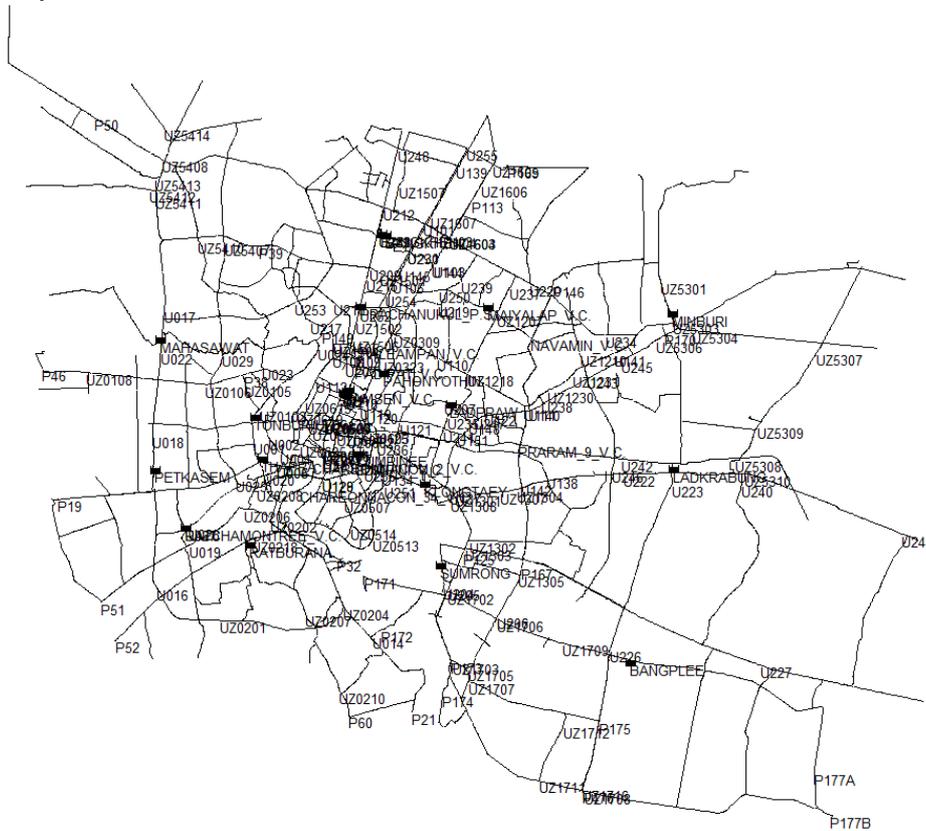
### 4 Metrology

MWA attempts to adjust the pipeline network model to reduce errors and calibrate with field measurements data. The calibrations were performed on the basis of pressures measured during 24 hours. Field measurements of water pressure at different points of the MWA network were conducted using flexible pressure transmitters. Data sets obtained from field measurements of water pressure were then used to calibrate the model predictions [5]. The locations of the field pressure measurement points are presented in figure 2. The majority of the main pipes of MWA (about 86%) are steel pipes and the diameters are 500-1800 mm. Units were set to metric system in EPANET and the head losses formula was set to Hazen-Williams.

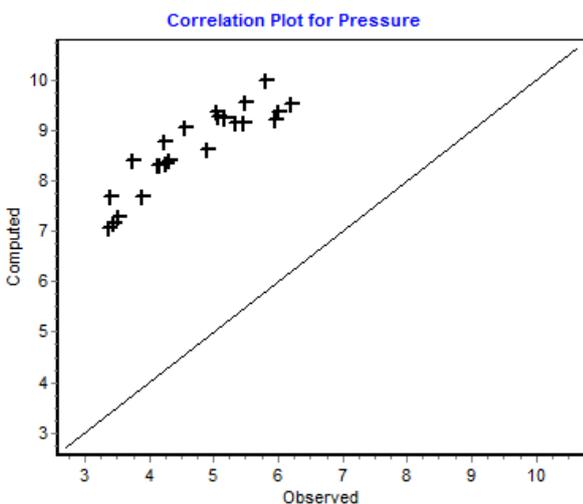
Hazen-Williams roughness coefficient of the pipes was considered to be 120 for all the pipes in the model. The base demand of the main pipe network used the demand of each DMA. The average mean absolute error was approximately 1.586 m and this showed the difference between that model predictions and measurements of pressure was quite high. The calculation results tended to be in the same direction as the measured

data, but there were still errors from many reasons such as the pipe friction factor, percentage of valve opening, wrong elevation of node etc. The calibration showed that the pressure measurements contained constant errors at many nodes, for example, in figure 3 which presents results obtained by the calibrated model for the

measurement point U014, one can see that the differences between the measured and modelled pressures oscillate around the average pressure 3.892 m. This error was caused by wrong elevation of nodes. This value is a constant error in terms of Eq. (3).



**Figure 2.** Field pressure measurement 134 points.



**Figure 3.** Correlation between computed and observed data of U014

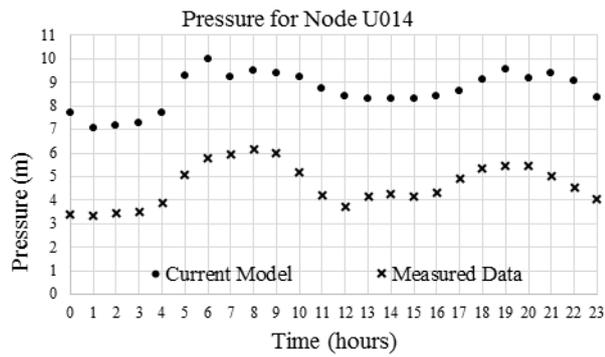
The current pipeline network model does not assign the elevation of the node, so the elevation equals 0 for all nodes. Although MWA's service area is relatively flat, the elevations vary between 0 to 2 meters above sea level. However, some points of the MWA's pipeline are higher than the normal pipeline, especially at bridges across the

many canals in MWA's service area as shown typically in figure 4.

Therefore, the pipeline at these points must be higher than the normal pipeline and these positions are often used to install a flow meter and a pressure transmitter. A pressure transmitter installed on the riser itself will indicate lower pressure than an installation in a pipe the normal level. When the water pressure from the field measurement is compared to the calculated water pressure, the pressure of the software is higher than the field measurement, as shown in figure 5.



**Figure 4.** Pipe laying across the canal



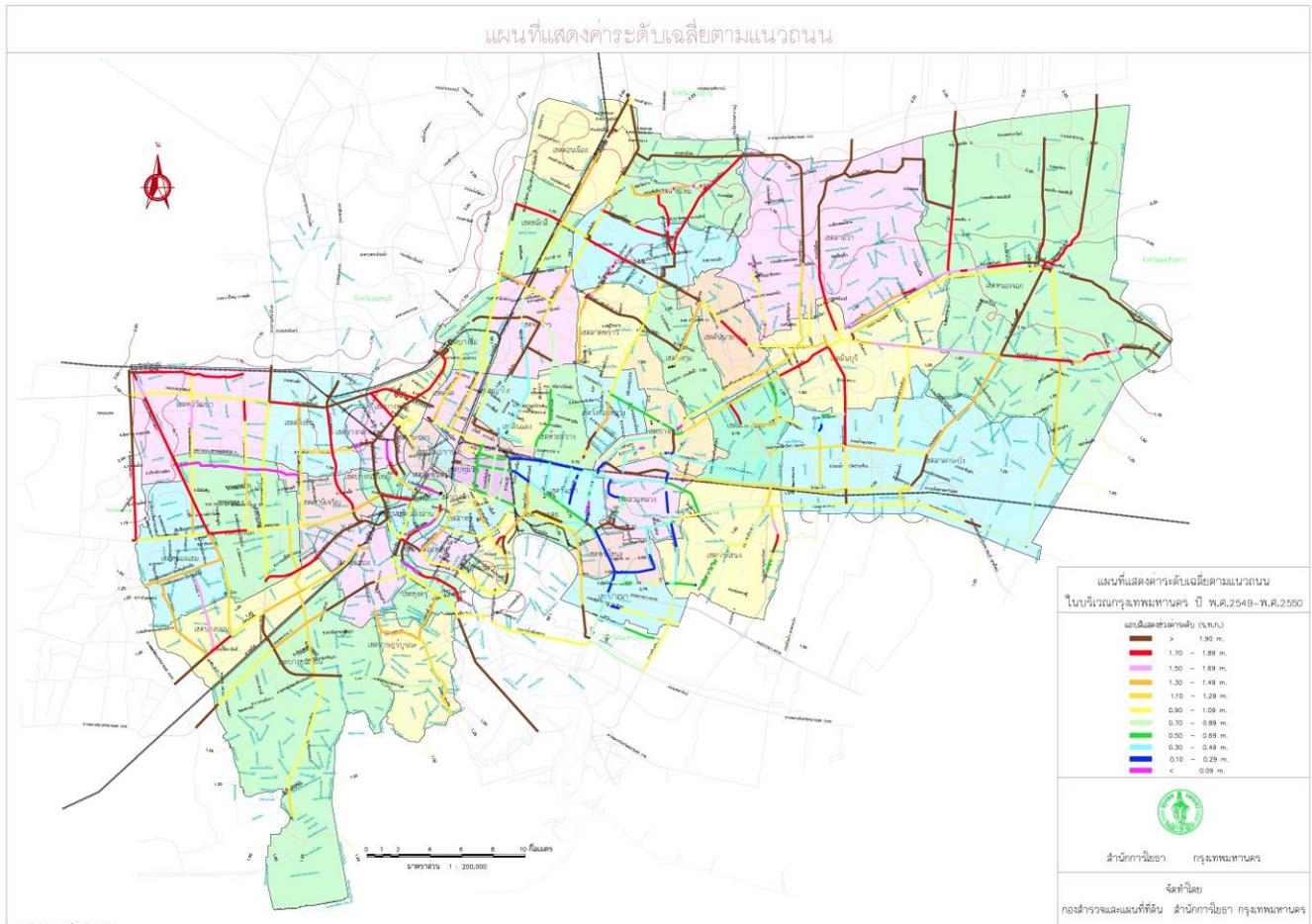
**Figure 5.** Computed results of current model and measured values for pressure at node U014.

Moreover, the head at each reservoir does not compensate for the elevation of each source. The head of these reservoirs is the fixed grade head, which is the source of data for calculation. When the source data is wrong, the result will be wrong. Therefore, the elevation of each node in the pipeline network model should be adjusted. Revision of node elevation can be referenced from the elevation of the roads as the main pipe is usually placed along the roads. Therefore, it is possible to estimate the elevation of the pipe line from the elevation of the roads, using data from the mean elevation map along the roads in Bangkok, 2006 – 2007 of Land Survey and Map Division, Public Works Department, Bangkok Metropolitan Administration. This is a map showing

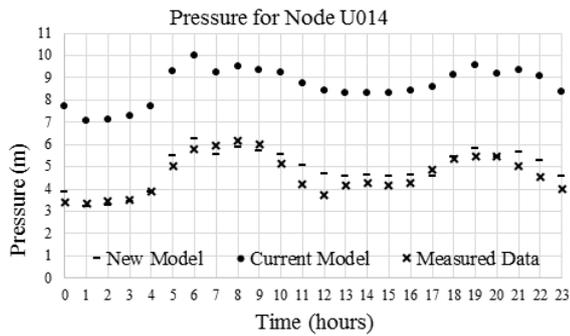
elevation values based on mean sea level (MSL) as figure 6. The elevations of roads vary between 0.09 to 1.90 meters above the sea level.

## 5 Result and discussion

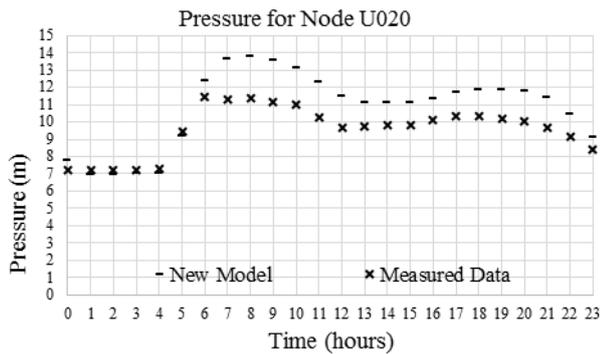
After adjusting the elevation of nodes in the pipe network model, the model was recalibrated by comparing with the 134 field measured pressure points. It was found that the new model was more accurate than the current model. The correlation between means was up to 0.893 from 0.803. For example, at the measurement point U014 the correlation between new mean was better than the current model as shown in figure 7, where it can be seen that the results almost coincide at all times. Although overall the new model is quite good, there are shift some points that have high error such as at point number U020. It is suspected that this error may be due to the selection of the Head losses formula. Upto now, the Hazen-William formula has been used to calculate the Head losses by setting the Chw value to 120. This is the suggested value for brand-new steel pipe only. In fact, pipes of MWA have been used for a long time, so the pipe roughness has changed and should be revised in the network model. The Darcy Weisbach formula should be used for better accuracy.



**Figure 6.** Bangkok roads elevation map.



**Figure 7.** Computed results from the current model, new model and measured values for pressure at node U014.



**Figure 8.** Computed results from the new model and measured values for pressure at node U020.

## 6 Conclusion

This study shows that it is necessary to assign elevation to each node in the network model, because the elevation

values affect the calculation of the pressure at each node, especially at a point where a water pressure gauge is installed. These elevations were used to recalibrate the model. As a result the new network model has better accuracy.

## Acknowledgement

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