Archives of Hydro-Engineering and Environmental Mechanics 70 (2023), pp. 17–28, doi: 10.2478/heem-2023-0002

sciendo

ARCHIVES OF HYDRO-ENGINEERING AND ENVIRONMENTAL MECHANICS

Published since 1954 ISSN 1231–3726

Simulation of Pipe Networks Using EPANET to Optimize Water Supply: A Case Study for Arjawinangun Area, Indonesia

Adam Safitri[1,2], **Slamet Imam Wahyudi**[1*], **Soedarsono**[1]

[1]Faculty of Engineering, Universitas Islam Sultan Agung Semarang, Raya Kaligawe Km. 4 Street, Semarang 50112, Indonesia;

[2]Civil Engineering Study Program, Sekolah Tinggi Teknologi Cirebon, 11 Evakuasi Street, Cirebon 45135, Indonesia;

[*]Corresponding author: e-mail: wahyudi@unissula.ac.id

(Received 29 September 2022; revised 17 March 2023)

Abstract. In providing clean water services to a community, a clean water supply distribution network system is very important. This study is aimed at the determination of the distribution pipe network by simulating and optimizing the water supply system in the Arjawinangun area, Cirebon, West Java, Indonesia. The data collected was analyzed by using EPANET 2.0 software for modelling water distribution systems. The results show that the total domestic and non-domestic water demand is 391.41 l/s, with a leakage rate of 20%. The pipeline installation plan for the Arjawinangun area is planned to be installed for a length of 23,045 m, with pipe diameters ranging from 400 to 90 mm. The Arjawinangun Area Offtake Reservoir drainage system, which is at an elevation of +25 m above sea level, requires a distribution pump with a head (H) of 6.0 bar. Also, using the gravity distribution technique, a water tower can be built (~ 55 m) as a water supply booster pump.

Key words: drinking water, EPANET 2.0, hydraulic simulation, optimization, pipeline network

List of Abbreviations and Units

PDAM: Perusahaan Daerah Air Minum/Local Water Company Service
ha: hectare
HC: home connection
PH: public hydrant
mH_2O: meters of water gauge/column
l/o/h: liter/person/day
l/h: liter/hour
l/s: liter/second
Q_{peak}: debit peak

Q_{mean}: debit mean
$Q_{\max.day}$: debit maximum day
Q_r: debit mean
LW: loss of water
PVC: Polyvinyl chloride
ACP: Asbestos Cement Pipe
DCIP: Ductile Cast Iron Pipes
PE: Polyethylene
BPPSPAM: Badan Peningkatan Penyelenggaraan Sistem Penyediaan Air Minum / Agency for the Improvement of Drinking Water Supply System Operations
HDPE: High Density Polyethylene

1. Introduction

Drinking water infrastructure is a requirement for sustainable community life (Zamzami et al 2018). The availability of a drinking water system greatly affects regional economic growth. It improves the quality of the local community and the natural environment (Admodjo and Sangkawati 2009). Problems with the drinking water systems are due to the gap between demand and service quality in urban and rural areas, the lack of drinking water supply facilities, inadequate infrastructure, inefficient management, and the lack of funds for development and management (Ali 2016). In providing clean water services to the community, a clean water supply distribution network system is very important (Sukadana 2017).

There is a lot of application software for analyzing water distribution networks, including the software helping to analyze piped water distribution networks known as the EPANET 2.0 program. EPANET is a computer software developed by the US Environmental Protection Agency Drinking Water Research Division, which can be applied to hydraulic modeling of a distribution network system. It comprises pipe nodes/junctions, pumps, valves, and reservoirs. Complete facilities and accurate hydraulic modeling are effective in modeling water flow and quality. The EPANET is a hydraulic analysis tool that possesses some analytical capabilities that are not limited to a network location. The program enables the calculation of pipe roughness using either the Hazen-Williams, Darcy-Weisbach, or Chezy-Manning equations, is capable of calculating the energy and cost of pumps, modeling of various types of valves including shut-off valves, and can check valves, pressure regulators and flow control valves, etc. (Rossman 2000).

EPANET 2.0 is very easy to use because it does not require high computer specifications. The main advantages of EPANET 2.0 software for distribution network analysis are: (1) the flow rate in the network is obtained by using a linear method, and (2) the pressure loss due to friction is calculated by applying the Darcy-Weisbach or Manning formulae. Yet another advantage of this software is that it is able to account for small losses and duplicate requests that vary over time, and it can handle different request patterns for each node.

Previous research by Sela et al (2019) was conducted by using the EPANET 2.0 to develop a simulation model for the clean water distribution system in Maros Regency. The EPANET 2.0 model requires several internal parameters to be entered to perform the simulation. These parameters are: water demand, elevation, pipe length, pipe diameter, pipe roughness coefficient, and others. The input data used in the simulation are the Hazen-Williams (C) roughness coefficient values, calculation of water demand, and determination of loading. The method which is used in the analysis is based on implementing a network performance simulation, in which the performance of the pipeline network and its facilities, including optimization of a pipe diameter, can be explained. The simulation has shown an idle capacity of 80% of the available water capacity (Sela et al 2019).

This research reports a case study for the Cirebon Regency in Indonesia. The company that manages public drinking water in this area belongs to the Government – the Regional Public Drinking Water Company (Perusahaan Daerah Air Minum – PDAM) Tirta Jati Branch Arjawinangun. This company serves the following districts: Susukan District, Kaliwedi District, and Arjawinangun District. Those areas demonstrate difficulty in accessing clean water, so the PDAM service is really important on a daily basis. PDAM Tirta Jati Arjawinangun serves drinking water with a distribution capacity of 50 l/s with 9,973 network pipes (as for February 2020) and 79,382 customers (Table 1).

Table 1. Clean drinking water plans

Residents (Thousand)	City type	Drinking water demands (liter/inhabitant/day)
> 2.000.000	Metropolitan	> 210
1.000.000–2.000.000	Metropolitan	150–210
500.000–1.000.000	Urban	120–150
100.000–500.000	Urban	100–150
20.000–100.000	Sub-urban	90–100
3.000–20.000	Rural	60–100

Source: Ministry of Public Works 1998

The EPANET program has been applied to predict the direction and flow rate in each pipe in the network, the pressure at each node, the water level in tanks, and the concentration of chemicals in the network during the simulation period (Rossman 2000). Hence, this study has aimed at simulating the distribution pipe network and its optimizing in terms of water supply in the area of Arjawinangun, Cirebon, West Java, Indonesia.

2. Method of Analysis

Based on Wahyuni and Affandy (2018), drinking water needs are divided into two purposes:

1) Domestic water needs, i.e., household needs, and
2) Non-domestic water needs: for industry, tourism, house of worship, social places, commercial places or other public places.

The quantity of water supply is based on the amount of raw water available (Finanda et al 2013). The amount of water which a community requires varies, depending on the geographical location, culture, economic level, technology, and a city's scale. Water needs are divided into household and non-household needs (Linsley and Franzini 1996).

Every flow of water in a pipe must follow the principle of continuity, where the flow that enters the pipe at one end is the same as the discharge that releases the other end of the pipe, with the discharge Equation (1) given below (Triatmodjo 2003):

$$Q = V \times A, \tag{1}$$

where Q is debit (m^3/s), V is flow velocity (m/s), and A is a pipe cross-sectional area (m^2).

Water supplied to consumers through transmission and distribution pipes serves and reaches customers as far as possible, with a minimum water pressure of 10 mH_2O (meters of water gauge/column) or 1 atm. The lowest remaining water pressure is 5 mH_2O or 0.5 atm (one atm = 10 m), and the highest is 8 atm, or an equivalent of 80 m (PDAM Tirta Jati 2018).

Daily average water requirement (Q_{av}) is the daily amount needed to fulfill domestic and non-domestic demands. The maximum daily requirement ($Q_{\max}$) is the largest amount of water needed in one day for a year calculation based on the value of daily average water needs, as presented by Equation (2) and Equation (3) (Rosadi 2011):

$$Q_{\max} = F_{\max} A_{av}, \tag{2}$$

$$F_{\max} = \frac{Q_{\max}}{Q_{av}}, \tag{3}$$

where $Q_{\max}$ is maximal daily drinking water demand (liter/second), $F_{\max}$ is a daily maximum factor ($1 < F_{\max}$ hour < 1.5), and Q_{av} is the average daily drinking water demand (liter/second).

In the water pipe network system, the clean water distribution generally is classified into three main systems (Joko 2010):

1) Branch system (branch)
2) Circular system (loop)
3) Gridiron system

2.1. Data Collection

This study is carried out in the Cirebon Regency, which exhibits an average population density of 140 people/ha. The highest density was in Weru District, which was 347 inhabitants/ha, and the lowest was in Pasaleman District with 44 inhabitants/ha (Fig. 1). The primary data, including elevation, pressure, and debit, and the secondary data, such as pipeline network map, customer number, logger data, pipes info, customer info, dan customer distribution map, is obtained from Local Water Company Service (PDAM), government institution, and observation.

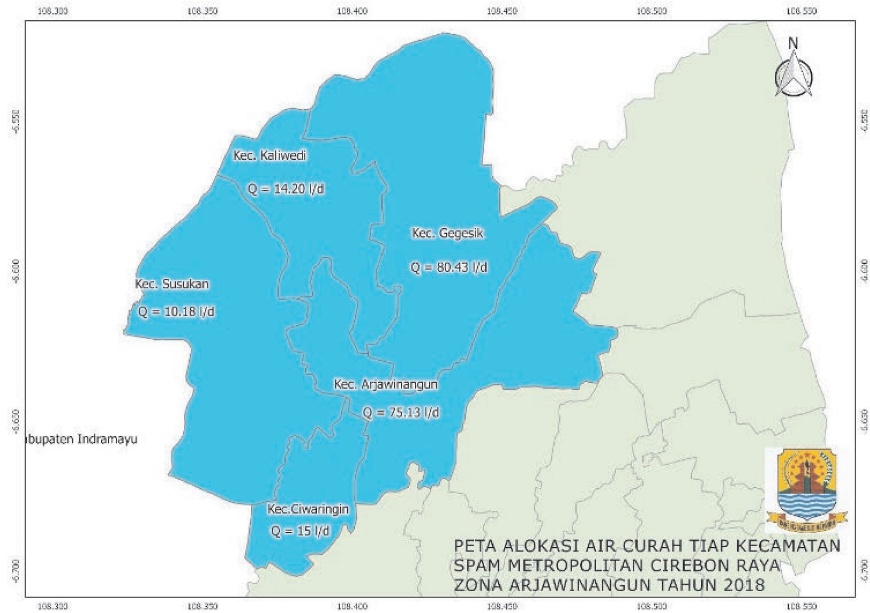

Fig. 1. The location of research (PDAM Tirta Jati 2018)

2.2. EPANET Simulation

To develop the water supply distribution network, we developed the following methodology (Fig. 2). The transmission and distribution pipeline criteria are presented in Table 2. According to the adopted criteria, this study is performed in a research location with a large population density, Cirebon Regency, which exhibits an average density of 140 people/ha. Simulations using the EPANET software were performed to determine the influence from inside the pipeline. Network component data for this simulation include nodes, pipes, reservoirs, and pumps. This stage is used to simulate the distribution of pipe networks. If there are no errors at this stage, then the data analysis process can be carried out. The process of data analysis produces hydraulic parameter data, such as pressure and velocity. These results are then converted into a file in the .dxf format, so that the analysis can be carried out later. The advantages of this software are the ability to analyze network placement, model pump speed, calculate pump energy and costs, and allow the inclusion of multiple demand categories at nodes. These pressure models depend on flow output and can be operated with a basic tank system and complex time control.

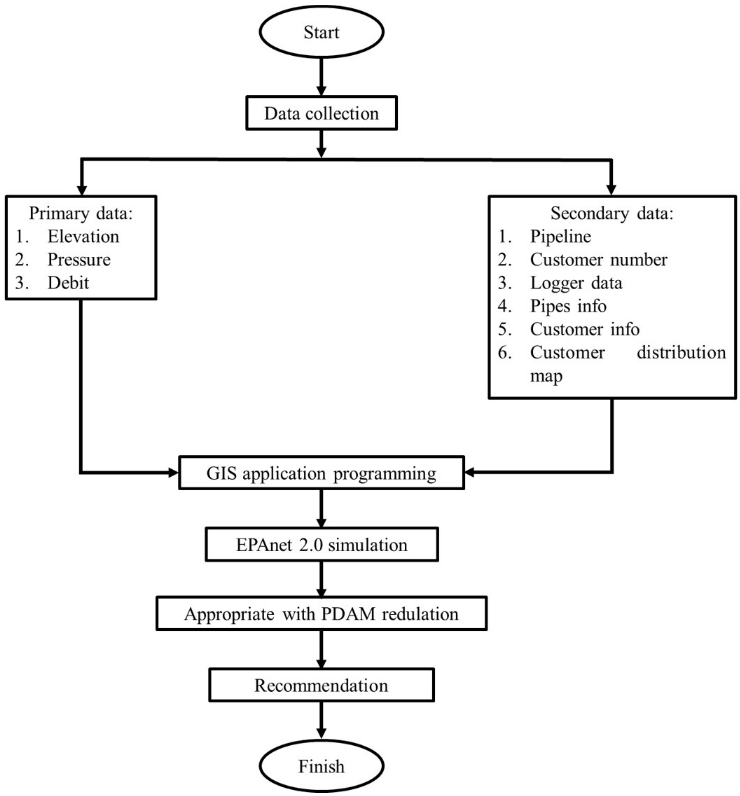

Fig. 2. Research scheme

3. Results and Discussion

Simulations were performed to calculate the population increase toward drinking water demands in the sampling districts. Results show that the geometry calculations method is the most suitable method to be used in the population estimation (Table 3), which is within PDAM Tirta Jati Arjawinangun service range. The calculation results of drinking water demand in the Arjawinangun area in 2033 are shown in Table 4.

Based on the estimated drinking water increase, the total demand for clean water in the Arjawinangun areas (including five districts with 363,664 inhabitants) in 2033 was evaluated to be 50,931 units of pipe HC and 1,091 PHs. The total domestic and non-domestic water demands are 391.41 l/s, with a leakage rate of 20%, and the

Table 2. The criteria of transmission and distribution pipeline

No	Parameter	Criteria
1	Plan water debit	Water demand during peak hours Q_{peak} = Peak factor × Q_{mean}
2	Peak hours factors – Main distribution pipeline – Carrier distribution pipeline – Divider distribution pipeline	1.15–3 1.15–1.7 2 3
3	Water flow velocity within pipes – Minimum velocity – Maximum velocity a) Polyvinyl chloride (PVC) or Asbestos Cement Pipe (ACP) pipe b) Metal pipe and Ductile Cast Iron Pipes (DCIP)	 0.3–0.6 m/second 3.0–4.5 m/second 6 m/second
4	The water pressure within pipes – Minimum pressure (tertiary) – Maximum pressure Pipe PVC or ACP Metal pipe or DCIP Pipe Polyethylene (PE) 100 Pipe PE 80	 (0.5–1.0) atm/bar at the farthest point of service coverage 6–8 atm 10 atm 12.4 Mpa 9 Mpa
5	Reservoir distributor effective volume	15%–25% *Q.max.day*
6	Standard water unit capacity	130% Q_r
7	Production unit capacity	110%–120% Q_r
8	Distribution unit capacity	115%–300% Q_r

Source: Ministry of Public Works 2007

Table 3. Population data and prediction of inhabitants in the District of Cirebon Regency

No	Service area (district)	Inhabitants	
		Total inhabitant	$P_n = P0(1 + r)n$
		2018	2033
I	Gegesik	81,580	106,611
II	Kaliwedi	43,810	57,252
III	Susukan	71,078	92,886
IV	Arjawinangun	43,725	57,141
V	Ciwaringin	38,088	49,774
	Total	278,281	363,664

20% water loss rate is the maximum recommended by Badan Peningkatan Penyelenggaraan Sistem Penyediaan Air Minum (BPPSPAM). However, reducing the water loss percentage to 0% is necessary. Conversely, the water loss percentage can be used to indicate the quality of drinking water. The quality needs improvement if it is higher than 20%. The Arjawinangun areas possess sloping geographical conditions, ~ ±5 m. Using gravity can be an advantage for pumping and distributing drinking water as far as possible.

Table 4. The prediction of drinking water demand in the Arjawinangun area in 2033

Prediction variable	Value
Total population	363,664 inhabitants
Total pipe home connection (HC)	50,913 HC
Total public hydrant (PH)	1.091 PH
Water daily demands	120 l/o/h
Total water demands	391.41 l/s
Water loss assumption	20%
Standard water capacity	1,549,98 l/s
Minimum reservoir capacity	10,000 m^3

3.1. Distribution Network Analysis

The distribution network analysis using the EPANET 2.0 program required elevation data to determine the drainage system and the population data that demand drinking water service. It required a map of the pipe network to be analyzed (Hassan and Masduqi 2014). The planning of the main distribution network is illustrated in Fig. 3. Next, as an output, the EPANET 2.0 model simulates the water pressure, water flow velocity, water discharge, and related parameters. Therefore, the results of the simulation by the EPANET 2.0 can be used as the basis for planning the Arjawinangun area pipeline network in order to improve the quality of distribution network criteria, in accordance with Ministry of Public Works Law no.18 of 2007 (Ministry of Public Works 2007) and Ministry of Public Works Law no. 122 of 2015 (Ministry of Public Works 2015). The analysis results of the pipeline network are presented in Table 5.

Table 5. Analysis result of the pipeline network in the Arjawinangun district of Cirebon Regency

Link ID	Length (m)	Diameter (mm)	Flow (LPS)	Velocity (m/s)	Unit headloss (m/km)
Pipe 2	1000	400	89.00	0.71	1.48
Pipe 3	891	100	5.00	0.64	6.12
Pipe 4	924	400	84.00	0.67	1.33
Pipe 5	3000	200	30.00	0.95	5.78
Pipe 6	266	200	10.00	0.32	0.76
Pipe 7	1500	160	20.00	0.99	8.08
Pipe 8	1273	160	7.00	0.35	1.16
Pipe 9	4433	110	5.00	0.53	3.85
Pipe 10	1000	90	2.00	0.31	1.87
Pipe 11	2000	300	54.00	0.76	2.38
Pipe 12	1881	300	50.00	0.71	2.06
Pipe 13	3826	250	50.00	1.02	5.02
Pipe 14	923	90	2.00	0.31	1.87
Pipe 15	488	90	2.00	0.31	1.87
Pump 1	# N/A	# N/A	96.00	0.00	−75.39

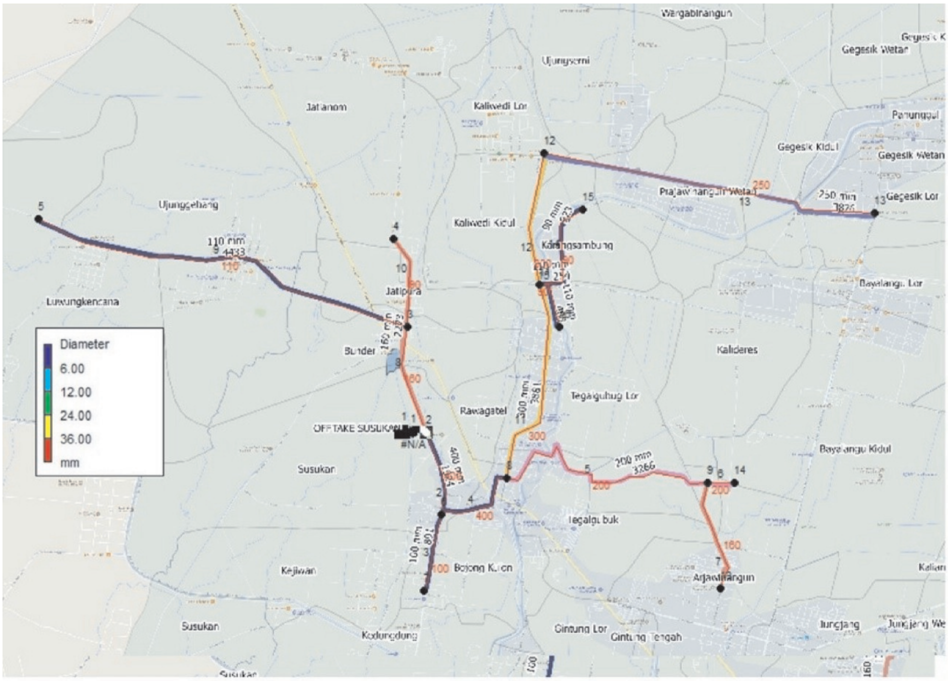

Fig. 3. The planning of the main distribution network

The main distribution pipeline plan for the Arjawinangun areas is illustrated in Fig. 4, which is then used to conduct simulations with the EPANET program to facilitate hydraulic analysis on the pipeline of the distribution service. The pipeline installation plan for the Arjawinangun areas is planned to be installed for a length of 23,045 m, with pipe diameters ranging from 400 to 90 mm. The pipe material used for the distribution pipelines is High-Density Polyethylene (HDPE) pipe, which exhibits longer durability.

The EPANET simulation results are shown in Table 6. With the sloping geographical condition, employing gravity to help distribute water is possible, using the push pump technique to reach the farthest service distance. The highest pressure at each connection point is 75.39 m, located at the connection point 2, and the lowest is 37.84 m at the connection point 13, so the value at each connection point can be calculated.

4. Methodology

In a streamwise direction, the momentum principle was applied to develop a discharge equation for submerged-flow conditions. This equation was first calibrated and then validated using a large set of experimental data from the literature (Prawel 1958, Thomas 1966, Zerihun 2004). The data were further analyzed to examine the effects of submergence on the local flow characteristics of a trapezoidal-shaped weir. Table 1

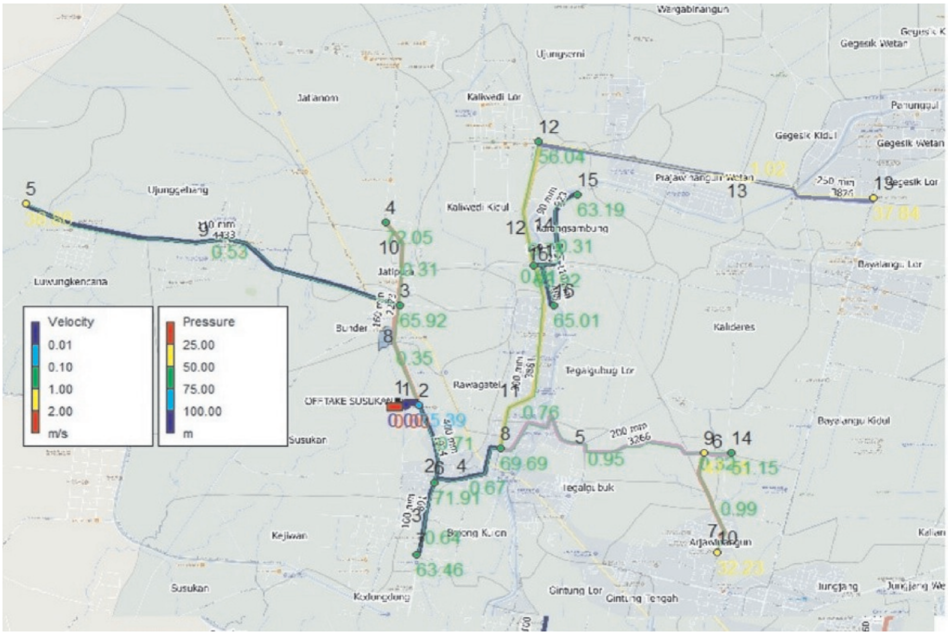

Fig. 4. The main distribution pipeline plan for the Arjawinangun areas

Table 6. Epanet Simulation result of water distribution in Arjawinangun area, Cirebon

Node ID	Elevation (m)	Demand ()	Head (m)	Pressure (m)
Junc 2	25	0.00	100.39	75.39
Junc 3	33	0.00	98.92	65.92
Junc 4	25	2.00	97.05	72.05
Junc 5	43	5.00	81.86	38.86
Junc 6	27	0.00	98.91	71.91
Junc 7	30	5.00	93.46	63.46
Junc 8	28	0.00	97.69	69.69
Junc 9	33	0.00	80.35	47.35
Junc 10	36	20.00	68.23	32.23
Junc 11	29	0.00	92.92	63.92
Junc 12	33	0.00	89.04	56.04
Junc 13	32	50.00	69.84	37.84
Junc 14	29	10.00	80.15	51.15
Junc 15	28	2.00	91.19	63.19
Junc 16	27	2.00	92.01	65.01
Resvr 1	25	–96.00	25.00	0.00

summarizes the flow conditions of the selected experimental studies. Also, the Froude number of the approach flow, F_{r0}, is estimated based on the flow parameters at the upstream end section. As shown in Table 1, it is relatively low due to the submerged overflow situation.

5. Conclusions

The drinking water supply system controls the process of supplying drinking water, starting from planning raw water sources (its quality and quantity) and transmitting raw water from an intake (raw water source) to the water treatment installation. The water installation managing the water distribution to society requires the best quality of performance and cost management to distribute drinking water. Technical and administrative matters related to the drinking water supply process are included in the drinking water supply system. Based on the EPANET 2.0 simulation, The Arjawinangun Areas Offtake Reservoir drainage system, which exhibits an elevation of +25 m above sea level, requires a distribution pump with a head (H) of 6.0 bar. Also, using the gravity distribution technique, a water tower can be built (~ 55 m) as a water booster pump. The simulation results achieved in this work can be used as a research material for the analysis of water distribution system optimization carried out by other institutions. Similar simulations can also be carried out in other areas that experience problems related to the water distribution system.

Acknowledgments

The authors thank Universitas Islam Sultan Agung Semarang for facilitating this research.

References

Admodjo P. S., Sangkawati S. (2009) Evaluasi dan Prediksi Pengelolaan Jaringan Air Bersih IKK Brangsong Kabupaten Kendal Berbasis Sistem Informasi Geografis dalam Rangka Mendukung Millenium Development Goals (MDGs), *Media Komunikasi Teknik Sipil*, **17** (1), 98–109, https://doi.org/10.14710/mkts.v17i1.3417.

Ali M. A. (2016) Pengembangan sistem jaringan distribusi air bersih di Kecamatan Turen, *Media Teknik Sipil*, **9** (2), 161–163, https://doi.org/10.22219/jmts.v9i2.1202.

Finanda R. D., Nurhuda S., Kadir A., Salamun S. (2013) Perencanaan jaringan distribusi air bersih Perumnas Banyumanik, Kota Semarang, *Jurnal Karya Teknik Sipil*, **2** (3), 116–122.

Hassan F., Masduqi A. (2014) Pemodelan penurunan sisa chlor jaringan distribusi air minum dengan EPANET (Studikasus Kecamatan Sukun Kota Malang), *Jurnal Teknik ITS*, **3** (2), 1–5 http://dx.doi.org/10.12962/j23373539.v3i2.7866.

Joko T. (2010) *Raw water unit in drinking water supply system*, Graha Ilmu, Yogyakarta.

Linsley R. K., Franzini J. B. (1996) *Water resources engineering*, Erlangga, Jakarta.

Ministry of Public Works (1998) *Technical guidelines for planning, implementation and supervision of urban drinking water supply system (SPAM) management*, Directorate General of Human Settlements, Jakarta.

Ministry of Public Works (2007) *Implementation of drinking water supply system development*, Directorate General of Human Settlements, Jakarta.

Ministry of Public Works (2015) *Drinking water supply system*, Directorate General of Human Settlements, Jakarta.

PDAM Tirta Jati (2018) *PDAM Tirta Jati Arjawinangun service range*, PDAM Tirta Jati, Cirebon, https://pdamtirtajati.com/.

Rosadi M. I. (2011) Planning for the development of distribution network system for PDAM IKK Durenan, Trenggalek Regency, *Master Thesis*, Sepuluh Nopember Institute of Technology, Indonesia.

Rossman L. A. (2000) *EPANET 2 user's manual, water supply and water resources*, Division National Risk Management Research Laboratory, Cincinnati.

Sela L., Salomons E., Housh M. (2019) Plugin prototyping for the EPANET software, *Environmental Modelling and Software*, **119**, 49–56, https://doi.org/10.1016/j.envsoft.2019.05.010.

Sukadana I. G. K. (2017), Perencanaan dan kajian teknis sistem perpipaan air bersih di Desa Kenderan-Gianyar, *Buletin Udayana Mengabdi*, **11** (2), 66–69.

Triatmodjo, B. (2003) *Hidraulika*, Beta Offset, Yogyakarta.

Wahyuni I., Affandy N. A. (2018) Sistem penyediaan dan distribusi air bersih di Desa Tlogoagung, Kecamatan Kembangbahu, Kabupaten Lamongan dengan EPANET 2.0, *Jurnal Teknika*, **10** (1), 993–998, https://doi.org/10.30736/teknika.v10i1.206.

Zamzami Z., Azmeri A., Syamsidik S. (2018) The clean water distribution network system for the freshwater PDAM, Central Aceh Regency, *Journal of Archive in Civil Engineering and Planning*, **1** (1), 132–141, https://doi.org/10.24815/jarsp.v1i1.10330.