A study of clean water distribution network development at PDAM Tirta Barito in the city of Buntok

Eka Wahyu Diana1, Mohammad Sholichin1, Riyanto Haribowo1

1Water Resources Engineering Department, Faculty of Engineering, Universitas Brawijaya, Malang 65145, Indonesia

E-mail: mochsholichin@ub.ac.id

Abstract. PDAM of the City of Buntok is the supplier of clean water needs for the areas of Buntok Kota, Hilirsper, and Jelapat Hamlets and Pamait Village. Population growth, water loss and utilization of discharge that has not been optimal have become obstacles in service. The aim of the research is to evaluate the existing distribution network and development plan until 2038 as viewed from the aspect of hydraulics and water quality using WaterCAD v8i software, as well as economic analysis to determine water prices. The available discharge is 10,000 l/s. Simulation of the existing condition produces pressure and headloss gradient that meet technical requirements, while velocity did not meet technical criteria. Water requirements for 2038 need an additional Water Treatment Plant with capacities of 30 l/s and 20 l/s. The simulation of development results met the technical requirements, being 0.3-4.5 m/s, a headloss gradient 0-15 m/km, and pressure of 0.5-8 atm. Further, the hydraulic model was used to analyse the concentration of residual chlorine. Injection at the tank inlet amounted to a constant 0.4 mg/l. Simulation of produced residual chlorine met the requirements from 0.383-0.395 mg/l. Economic analysis resulted in a water price of Rp. 6,100.00/m³, BCR 1.23, IRR 12.14 %, and BEP of 11 years. Based on the willingness to pay being Rp. 4,200.00/m³, the value of required government subsidies is Rp. 13,905,747,800.

Keywords: clean water, pipe network, residual chlorine, water prices

1. Introduction

Water is an essential need that affects many aspects of human life. Water supports human life, if managed properly. Population growth, lifestyle changes, decline in ecosystem services, and climate change can reduce access to water of adequate quality and quantity, as well as increase variability and magnitude of extreme events. Lack of access to fresh water and increasing risks of extreme events will make it more difficult to achieve sustainability of water resources [7]. The factor of climate change and access to distribution influence the sustainability of fulfilling clean water needs even though the availability of water is quite large, and this has an impact on water organizations that are tasked for the management of the social and ecological needs for water [1].

Water distribution network development planning is required to collect information on the physical characteristics of a system and determine the level of consumption, as a process that requires a study of past, present and future usage trends. After the consumption level is determined, the use of water is spatially distributed as the required load for modelling the node. This process is referred to as “loading the model”. The model can be used to solve ongoing problems, analyse proposed operational changes, and prepare for unusual events. By comparing the results of the model with field operations,
the operator can determine the cause of problems in the system and formulate a solution that will function correctly from the start, instead of going through trial and error in the actual system [9].

The network model plays an important role in the design, operation, and management of water distribution systems [6]. This research simulation uses the WaterCAD V8i program to analyse the hydraulic conditions in the water distribution network by calculating the flow and pressure in pipe network that is relatively modelled. WaterCADV8i is a hydraulic modelling software that consists of various functions including flexible graphical and profile progress. Many features such as hydraulic and water quality analysis, as well as steady state and long-term simulations, are also made to function with enhanced capabilities and strong data management along with the integration of AutoCAD and GIS. The advantages of WaterCAD V8i compared to other software include the making of simplified models with geospatial modules and tools such as Load Builder and TRex, water quality modelling, flow analysis, optimization, and scenario management. WaterCAD V8i is easily used for various types of water distribution as well as quality modelling software packages accepted for various applications [8]. The purpose of this study is to realize a network development system that is able to serve up to 2038. The benefit is as input for PDAM Tirta Barito in order to improve clean water distribution networks and support the fulfilment of clean water that is equitable and well distributed in the City of Buntok.

2. Materials and Methods

The study began by evaluating the condition of the existing clean water distribution network and the network development plan with water demand until 2038, and the water quality aspect simulated chlorine injection to kill pathogenic bacteria to maintain water quality and make it suitable for consumption, while economic feasibility were in terms of NPV, BCR, BEP, and IRR.

2.1. Study Area

The study area is shown in Figure 1 with the service area of the PDAM of City of Buntok for the BNA Buntok Service Zone covering 3 hamlets and 1 village, which are the Buntok Kota, Hilir Sper, and Jelapat Hamlets and Pamait Village with a service area of 215 km². The production capacity is 85 l/s and geographically lies within 1°20’ NL – 2°35’ SL and 114° – 115° EL. The topography of the South Barito Regency is a relatively low-lying area. The water source is obtained from the Barito River. The drainage system utilizes a pump. The capacity of the clean water treatment plant is 85 l/s and the reservoir capacity is 1000 m³.

| Table 1. Load factor (LF) on Daily Needs |
|-----------------------------------------|
| Hour | LF | Hour | LF | Hour | LF |
| 1    | 0.31 | 9    | 1.42 | 17   | 1.31|
| 2    | 0.37 | 10   | 1.38 | 18   | 1.38|
| 3    | 0.45 | 11   | 1.27 | 19   | 1.25|
| 4    | 0.64 | 12   | 1.2  | 20   | 0.98|
| 5    | 1.15 | 13   | 1.14 | 21   | 0.62|
| 6    | 1.4  | 14   | 1.17 | 22   | 0.45|
| 7    | 1.53 | 15   | 1.18 | 23   | 0.37|
| 8    | 1.56 | 16   | 1.22 | 24   | 0.25|

| Table 2. Pipe Criteria |
|-------------------------|
| Criteria | PVC Pipe |
| Velocity  | 0.3-4.5 m/s |
| Headloss Gradient | 0-15 m/km |
| Pressure | 0.5-8 atm |
2.2. Data Collection

The following are the data used in this study:
1. Population data for 2009-2017 of South Barito Regency
2. Map of PDAM Tirta Barito's existing pipeline in the City of Buntok and topographic data
3. Data on the number of Residential Connections
4. Data on the quality of water produced
5. List of unit prices of wages and materials in South Barito Regency in 2018
6. Data on the willingness to pay, obtained through questionnaires

Figure 1. Study Area

2.3. Data Processing

1. Population was predicted using calculations by the geometric method, the arithmetic method, and the exponential method [5]. The masterplan for the drinking water distribution network was prepared for a period of 15-20 years [3]. In this study, population prediction was carried out for 20 years from 2019-2038.
2. The values of correlation coefficients are compared to test the suitability of the population prediction method.
3. Needs for clean water are calculated.
   - Based on the population, the City of Buntok is included in the category of a Small City with clean water needs amounting to 130 l/person/day [3]
   - Non-domestic needs are equal to 15% of domestic needs [10].
   - Water loss is equal to 20% [10].
   - There are fluctuations in clean water requirements (Table 1).
4. Analysis of the needs and availability of clean water was performed by dividing the water needs at each junction, by adjusting the data for Residential Connections from the PDAM of the City of Buntok for each network in the service area. The prediction results of 2038 water discharge needs that were simulated using the Bentley WaterCADv8i software became the basis for the distribution network development plan.

5. Analysis of economic feasibility involved:
- Benefit Cost Ratio (BCR)
  BCR calculation used the formula [2]:
  \[ BCR = \frac{PV \text{ Benefit}}{PV \text{ Cost}} \]  
  (1)
  Where:
  \( PV \) = Present Value
  \( BCR \) = Benefit Cost Ratio
- Net Benefit (\( B-C \)) is the difference between the amount of benefits and the amount of costs.
- Internal Rate of Return (IRR):
  The IRR value is calculated by the formula [4]:
  \[ IRR = I + \left( \frac{(B-C)}{(B-C)'} \right) \left( I'' - I' \right) \]  
  (2)
  Where:
  \( I' \) = interest rate with a positive (B-C) value
  \( I'' \) = interest rate with a negative (B-C) value
  \( (B-C)'' \) = positive net benefit (B-C)
  \( (B-C)'' \) = negative net benefit (B-C)
- Calculation formula for breakeven investment [2]:
  \[ k = \frac{\text{investment}}{\text{annual profit}} \times \text{time period} \]  
  (3)
  Where:
  \( k \) = return period
  Investment = capital used
  Annual profit = profit per year
  Time period = year
- Analysis of sensitivity was performed with a condition of a 10% decrease in benefits, a 10% increase in costs, and a delay in project completion.

6. Water price was determined per m\(^3\) for the PDAM of the City of Buntok.

3. Results and Discussion

3.1. Population Prediction and Analysis of Water Supply Needs and Availability
The total population at the end of 2018 was 37,117 people. The prediction results of the population in the service area up to 2038 is 48,896 people, and the result was used as the needs of the development plan for the needs of each region as well as for the average water requirements presented in Table 3.

Seen from Table 3, the analysis of needs for clean water resulted in the average amount of needs in the existing area of 55.95 l/sec, a maximum daily requirement of 64.34 l/sec, water demand at peak hours of 87.28 l/sec, and a production discharge of 85 l/sec. Thus, the discharge is not met during peak hours and requires additional production capacity.

The availability of raw water source discharge is 10,000 l/sec. As the average population discharge needs are equal to 55.95 l/s with 20% water loss, 100% of the people can still be served. In 2038, the average requirement amounts to 101.53 l/s with the available water discharge still being sufficient to meet the clean water needs of the people of the City of Buntok, and there was still residual discharge. The PDAM Clean Water Treatment Plant capacity of the City of Buntok amounted
to 85 l/sec, which is unable to meet the average, maximum and peak water needs; to optimize the service, an additional 2 units need to be installed, with capacities of 30 l/s and 20 l/s respectively.

Table 3. Prediction of Water Needs until 2038

| No | Years | Q Produksi (l/s) | Reservoir Capacity (l/s) | Water Demand (Q) | Water Demand (%) | Information |
|----|-------|-----------------|--------------------------|------------------|-----------------|-------------|
| 1  | 2018  | 85              | 1000                     | 55.95            | 64.34           | 87.28       | 76.18 Deficit on Peak Hours |
| 2  | 2023  | 85              | 1000                     | 74.09            | 85.21           | 115.59      | 100 Deficit on Minimum Hours and Peak Hours |
| 3  | 2028  | 85              | 1000                     | 79.17            | 91.04           | 123.50      | 100 does not meet |
| 4  | 2033  | 85              | 1000                     | 95.00            | 109.25          | 148.21      | 100 does not meet |
| 5  | 2038  | 85              | 1000                     | 101.53           | 116.76          | 158.38      | 100 does not meet |

3.2. Existing Condition Evaluation and Simulation of the WaterCAD V8i Program

Figure 2 shows the existing network model of the PDAM of the City of Buntok, with transmission pipes made of galvanized iron pipes and PVC-type distribution pipes, as well as surface water sources to serve the needs of clean water with a Barito River potential discharge equal to 10,000 l/sec. The installed clean water production IPA capacity equal to 85 litres per second from the PDAM of Buntok serves three hamlets and one village: Buntok Kota Hamlet, amounting to 66.13%, Hilir Sper Hamlet, amounting to 79.06%; Jelapat Hamlet, amounting to 67.96%; and Pamait Village, amounting to 31.55% with a distribution network length of 55,575 km to serve 6,128 Residential Connections. The water source is located at elevation +6m. The drainage of water distribution from the reservoir to the service area (junction) uses a pump because the Buntok City topography is relatively flat. To serve the water needs, the PDAM of the City of Buntok used two pumps located at the source with capacities of 60 l/s and 40 l/s respectively, while 4 distribution pumps are installed in parallel after the ground reservoir with the capacity of each being 100 l/s, 60 l/s, 40 l/s and 20 l/s. The pump working hours are 24 hours and the assumed water requirement is 130 l/person/day.

Figure 2. Distribution Network System Scheme
Figure 3 shows the velocity of the pipeline; there are several points where the velocity is less than 0.3 m/s and is not in accordance with the standards of the technical planning criteria for the provision of drinking water, which ranges from 0.3 to 4.5 m/s. For this reason, it is necessary to change the pipe diameter in several locations so that the velocity can be in accordance with the criteria standard.

Figure 4 shows the general headloss gradient analysis for existing conditions at peak hours, which meets the technical planning criteria with a limit of 0-15 m/km. Figure 5 shows the results of the simulation of the existing pressure conditions at minimum hours ranging from 4.08-5.20 atm and at peak hours ranging from 3.98-5 atm. These results are in accordance with the planning criteria (0.5-8 atm).

3.3. Development Conditions Plan
Development is carried out for the next 20 years, up to 2038. The existing clean water production capacity equal to 85.30 l/s cannot meet the needs of clean water for each type of clean water needs, requiring 2 additional clean water treatment plant units with capacities of 30 l/s and 20 l/s respectively. The reservoir capacity of 1000 m$^3$ up to 2038 is still able to meet the needs of the reservoir volume, and therefore no additional capacity is needed. To find out the accurate amount of production water that is distributed to customers, PDAM Tirta Barito should install a master water meter to measure the production of water that has been distributed as well as to determine trends or fluctuations in daily use for 24 hours at the PDAM of the City of Buntok.

In Figure 6, the simulation of pipe flow in general for the development conditions at minimum hours shows that the velocity in the pipe network ranges from 0.02-0.4 m/s, which does not meet the planning criteria of 0.3-4.5 m/s. The velocity in the pipes at peak hours ranges from 0.3-2.3 m/s and meets the planning criteria of 0.3-4.5 m/s.
Figure 7. Graph of Headloss Gradient of Development Conditions at Peak Hours

Figure 8. Graph of Headloss Gradient of Development Conditions at Minimum Hours

Figure 8 shows that the general flow of pipes for development conditions at peak hours has a headloss gradient in accordance with the planning requirements, ranging from 0-15 m/km. Figure 9 and Figure 10 show that the pressure at minimum and maximum hours met the technical planning criteria for drinking water, ranging from 0.5-8 atm.

Figure 9. Graph of Node Point Pressure of Development Conditions at Peak Hours

Figure 10. Graph of Node Point Pressure of Development Conditions at Minimum Hours

Liquid chlorine (NaOCl) or sodium hypochlorite is used in the disinfection process. Simulation of its quality was performed with the method of chlorine injection at the reservoir inlet with a constant dose of 0.4 mg/l until reaching the expected residual chlorine limit.

The results of this injection simulation showed that the residual chlorine of peak hours ranged from 0.387 – 0.399 mg/l, and of minimum hours ranged from 0.383 mg/l – 0.395 mg/l. This value is included in the criteria requirement of 0.3 mg/l ≤ residual chlorine ≤ 0.5 mg/l. In the first-day operations of the pipeline network, the water can only be used after 06.00, because it is only after 07.00 that all the junctions meet the requirement for the residual chlorine criteria and the simulation results on the following day experienced residual chlorine in accordance with the residual chlorine limit.

Figure 11 shows the simulation results of residual chlorine with the WaterCAD V8i program at peak hours on the first day, for pipes in the distribution pipeline to the right direction of the reservoir, J-2 to J-30. The concentration of residual chlorine will decrease with increased distance from the tank/reservoir to the junction. At J-2 the residual chlorine concentration was 0.3994 mg/l, at J-22 it dropped to 0.3990 mg/L, and at the furthest point of J-30, the concentration of residual chlorine decreased to 0.3982 mg/L.
3.4. Economic Analysis

The following are the project costs needed for the development plan of a clean water distribution network system for the PDAM of the City of Buntok:

- The required capital is Rp. 13,905,747,800, which consists of direct costs amounting to Rp. 12,360,664,700 in the form of additional construction costs at the processing installation and distribution units as well as indirect costs of Rp. 1,545,083,100,00.

The capital costs are added to the construction costs toward the construction that has been built, for which the next conversion to annual value amounts to Rp. 2,395,089,196.

- Annual costs that represent operational and maintenance (OP) costs used by the PDAM of the City of Buntok for processing and administrative costs and employee salaries amount to Rp. 6,837,076,381.

The interest rate used for economic analysis of the development project of clean water supply system in PDAM of Buntok City is a bank rate of 6%, for review of the values of BCR, B-C, IRR, breakeven point of investment and sensitivity analysis.

Table 4 shows the minimum water price when B=C with various interest rates. Economic analysis and sensitivity analysis considers that B = C. The water prices as determined for this study are based on the most critical conditions, being that when costs increase by 10%, benefits decrease by 10%; therefore, the resulting minimum water price tariff is equal to Rp. 6,100.

| Interest rate % | Benefit Water Production m³/year | Cost (Annual Cost) | Water Prices Rp/m³ |
|----------------|---------------------------------|-------------------|-------------------|
| 6              | 1,947,215                       | 9,642,390.161     | 4.952             |
| 7              | 1,947,215                       | 9,933,248.852     | 5.101             |
| 8              | 1,947,215                       | 8,263,282.593     | 4.244             |
| 9              | 1,947,215                       | 10,546,989.354    | 5.416             |
| 10             | 1,947,215                       | 10,869,339.939    | 5.582             |
| 12.5           | 1,947,215                       | 11,718,037.929    | 6.018             |
| 13             | 1,947,215                       | 11,894,707.027    | 6.109             |
| 14             | 1,947,215                       | 12,255,237.027    | 6.294             |
| 15             | 1,947,215                       | 12,624,163.738    | 6.483             |

The results of economic analysis showed that the BCR value is 1.23 and can be said to be feasible because BCR > 1. B-C had a positive value of Rp. 52,124,345 and is considered appropriate. This project is considered profitable because it has an IRR value of 12.14% and its value is greater than the BI interest rate of 6%. The breakeven point of investment occurs in the 11th year (in 2030).
The sensitivity analysis results for 6-14% interest rates showed that B/C > 1. Therefore, based on the results of the economic analysis and the sensitivity analysis, it was concluded that the clean water system development project can be said to be feasible to be built.

3.5. Determination of Water Prices Based on Willingness to Pay

Based on the analysis of the average WTP calculation of the people in the service area of PDAM of the City of Buntok, the amount that people are willing to pay is Rp. 4,200. Therefore, the government can provide subsidies so that the people are able to buy water. The value of the subsidy as the costs for the construction needs of PDAM of the City of Buntok is 13,905,747,800.

4. Conclusion

The results of the hydraulic analysis of existing conditions for pressure and headloss gradient meets the technical criteria while the velocity does not meet the planning standard, which disrupts the distribution of clean water at the study site; therefore it is necessary to change the pipe diameter. The availability of raw water discharge source is equal to 10,000 l/s, while with the average population needs of 101.53 l/s with 20% water loss, the availability of raw water can still serve 100%. The available water discharge is still sufficient to serve the clean water needs of the people of the City of Buntok until 2038.

For the development of clean water pipelines in PDAM of the of City Buntok, additional clean water treatment plants need to be installed with amounts of 30 l/s and 20 l/s, which are made available in stages in accordance with the needs of clean water. Based on the WaterCAD V8i simulation, it is concluded the pipeline has hydraulic conditions that meet technical criteria, even though the flow velocity at minimum hours is too slow.

The quality of the water produced by the PDAM installation of the City of Buntok is in accordance with the criteria. The disinfection process using liquid chlorine or sodium hypochlorite (NaOCl) is needed to maintain water quality is. The injection placed at the reservoir inlet amounts to a constant 0.4 mg/l.

The results of economic analysts showed water prices equal to 6,100.00/m³ with IRR of 12.4% and BEP of 11 years. WTP analysis indicated a price of Rp. 4,200.00, which means that a government subsidy is needed for the people to be able to purchase clean water.

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