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Transmission Pipeline Planning from Kregan Water Treatment Plant to Watu Gadjah Tank by PERUMDA PDAM Sleman Using EPANET 2.2

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ABSTRACT

Clean water is vital as it directly impacts health and influences various aspects of life, including social, economic, and cultural activities. To address the clean water supply requirements in the area, PERUMDA PDAM Sleman, Yogyakarta, is currently planning for a transmission network linking the Kregan WTP to the Watu Gadjah Tank. The pipeline planning is carried out to ensure efficient and optimal network performance. The pipeline planning use both primary and secondary data. The primary data was obtained from surveys, while the secondary data was obtained though previous research and planning, regulation, and from the other sources. The pipeline network analysis carried out using EPANET 2.2. software. EPTANET was selected because of its cost-effectiveness and robust capabilities in modeling drinking water networks, with the advantage of being re-programmable. The results of the analysis are then adjusted to the planning standards that applicable in Indonesia. Risk analysis was carried out based on experience and expert opinion. The results of the planning showed that the maximum pressure on the transmission network was 84.21m on Pendowo Road. The velocity between 1.03 m/s and 1.63 m/ss with the highest headloss was 10.33 m/km. Based on the results of the planning, the entire parameter meets the standard of the applicable planning criteria. The results of the analysis indicate that the technical specifications of the pipe used must be able to withstand a pressure of 92,63m. There was a potential risk that network performance may be disrupted both in terms of network performance, implementation of development, and operational stages. The re-examination and the development of operational standard procedures is needed to ensure that planning has been in line with the expectations, can be implemented, and can be operated efficiently.

1. Introduction

Humans cannot live without water. Water is the most abundant component of the human body and required for bodily metabolism [1]. The fulfillment of water needs and its quality are essential to maintaining bodily functions and enabling activity. Meeting water requirements is crucial because, ultimately, access to clean water not only affects health but also impacts social, economic, cultural, and all human activities [2]. The use of water resources needs to be regulated to prevent water shortages and exploitation that could lead to environmental problems [3]. Managing water resources includes ensuring that distribution networks remain uncontaminated [4].

The Indonesian government must ensure the water needs of the community through regional drinking water companies. This is crucial for achieving Indonesia's vision for 2045, where one of the targets is fulfilling SDG number 6 on clean water and sanitation. Among the essential components is the distribution unit, which plays a critical role in transferring water from the production unit to the consumer [5]. It is imperative that the network carries clean water, free from contamination [6], and that there are no leaks that could disrupt network performance [7]. The performance of water networks in Indonesia is regulated by laws, necessitating network planning that adheres to applicable criteria and standards [8].

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Planning a piping distribution network can be conducted either through manual analysis with manual calculations or by utilizing applications. Hydraulic modeling, as well as water quality assessment in transmission and distribution networks, typically involve the use of EPANET applications [9]. The transmission network is responsible for conveying water from its source to the treatment facility, and then from the treatment facility to reservoirs, tanks, or distribution points. In specific scenarios, a pressure-relief mechanism is necessary to prevent pipe ruptures or leaks caused by excessive pressure. Leakage can lead to a decrease in the quality of the water being transported [6].

A drinking water company in Sleman, Yogyakarta, is undertaking the planning of a transmission network in areas with high elevation conditions. Significant elevation differences can lead to high pressure, which in turn can result in pipe breakages [10]. Hence, meticulous planning of the transmission network is essential to support the distribution of drinking water to the community. It is imperative to develop plans that adhere to relevant standards specific to the study site and to identify potential hazards that may affect the network.

2. Method

The research was conducted in Sleman Regency, Yogyakarta Special Region Province, Indonesia, with data collection and analysis scheduled for December 2023. The methods used in this study will be outlined as Figure 1.

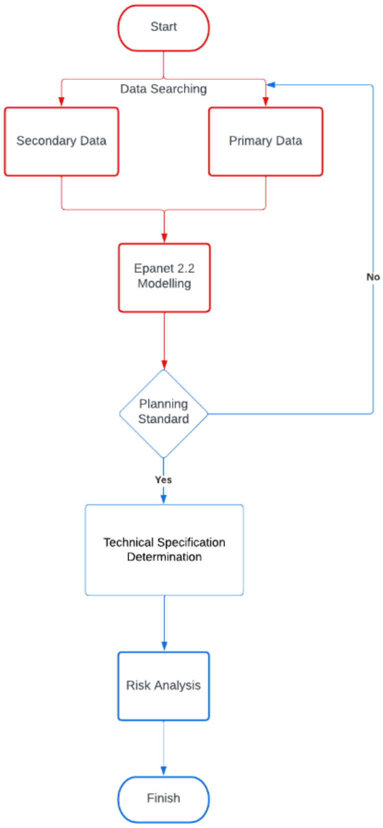

Figure 1. Research flowchart

2.1 Data Collection

The data utilized in this study comprised two (2) types: primary data and secondary data. Data collection was conducted collaboratively with the drinking water company to ensure synchronization between the parties. Primary data was gathered through direct field measurements, while secondary data was sourced from existing documents, regulations, and company planning criteria.

Primary data collected in the field and through GIS included coordinates, elevation, geographical surroundings, cable network maps, drainage maps, and the condition of the area surrounding the planned transmission pipeline. Field data collection, particularly for coordinates and elevation, utilized specialized tools. GIS applications were employed to process field data into informative datasets as part of data calibration efforts [11]. These data then used as coordinates in determining points or nodes within the EPANET 2.2 application.

Secondary data obtained from literature reviews encompassed previous planning documents, research articles, case studies, technical drawings, regulations, and company business plans. Secondary data aided in establishing planning criteria, inputting data into EPANET, referencing approved pipeline plans from local governments, and providing additional supporting information.

The collected data underwent processing and served as the foundation for transmission network planning. Processed data was utilized throughout various stages, including EPANET modeling, ensuring compliance with planning criteria, determining technical specifications, and conducting risk analysis.

2.2 EPANET Modelling

The EPANET application was selected due to its reliability and availability as a free hydraulic analysis tool. EPANET is capable of conducting simulated hydraulic and water quality analyses [5]. EPANET modeling necessitates fundamental and dependable data, as the initial data serves as the foundation for simulating the operation of a transmission and distribution network. The required delineation includes nodes based on coordinates, the piping network according to the path taken, and reservoir points

[12]. Data necessary for analysis comprise the headloss formula, unit settings, elevation, discharge, and pipe specifications. Inputs for pipes in EPANET include pipe length, inner diameter, and pipe roughness. Pipe length can also be determined from the distance between the coordinate points of nodes.

Modeling is carried out by converting the unit of analysis into the LPD international system of units. The headloss formula used is the Hazen-Williams (Equation 1).

$$h_f = 4.727\, C^{-1.852}\, d^{-4.871}\, L \quad (1)$$

with the headloss (h_f) in a pipe system, measured in feet, can be calculated using the Hazen-Williams equation, where *C* represents the roughness coefficient of the pipe, *d* is the diameter of the pipe in feet, and *L* is the length of the pipe in feet. The headloss is an important parameter in fluid flow analysis as it indicates the pressure drop along the pipe due to friction.

This equation corresponds to the calculation formula utilized in the EPANET application [13]. Planning involves inputting coordinate data, enabling automatic pipe length adjustments based on the coordinates.

Data input at the reservoir includes total head data, while data input at the node comprises elevation and base demand at the location of the Watu Gadjah Tank. Data input for pipes includes diameter and roughness. According to the permit and business plan specifications, the pipe diameter is 315 mm, with sections of the pipe constructed from cast iron and HDPE with a Hazen-Williams roughness coefficient of 130. It's important to note that the condition and age of the pipe can impact its roughness. New pipes typically have a smoother surface, resulting in a higher Hazen-Williams roughness coefficient [14].

EPANET analysis is conducted in single units as transmission network planning does not involve fluctuations in demand discharge. Consideration is given to the use of pumps and harnessing gravity based on the performance results of the EPANET network. An analysis of the EPANET network, configured accordingly, is performed, with the output results serving as considerations for subsequent steps. Output results from the EPANET analysis include tables, graphs, and mapping data.

2.3 Transmission Network Criteria

Planning criteria are adjusted to the type of pipe used. Transmission pipelines have different planning criteria than distribution pipelines [15]. In accordance with the REGULATION OF THE MINISTER OF PUBLIC WORKS, the summarized criteria are presented in Table 1.

Table 1. Transmission pipe planning criteria [15]

No.	Description	Symbol	Pipe standars
1	Discharge design	Q_{max}	F_{max} x $Q_{average}$
2	Maximum day factor	F_{max}	1.10 – 1.50
3	Peak hour factor	F_{Peak}	
4	Channel type	-	Pipe or open channel
5	Flow velocity in the pipe		
	a. Minimum Velocity	V_{min}	0.3-0.6 m/sec
	b. Maximum Velocity		
	PVC or ACP Pipe	V_{max}	0.3-4.5 m/sec
	Steel or DCIP Pipe	V_{max}	0.3-6 m/sec
6	Water pressure in pipes		
	a. Minimum Pressure	H_{min}	1 atm
	b. Maximum Pressure		
	PVC pr ACP	H_{max}	6-8 atm
	Steel or DCIP	H_{max}	10 atm
	Pipa PE 100	H_{max}	12.4 MPa
	Pipa PE 80	H_{max}	9 MPa

The criteria in Table 1 must be fulfilled; if not, then it is necessary to make network engineering so that the analysis on the EPANET application can change, which can be done by adding a valve [13]. The use of valves in the EPANET will later also be applied in the field, so the valve installation location needs to be surveyed again. This is carried out until it reaches the planning criteria.

2.4 Technical Specification Determination

Technical specifications are determined based on the network performance results in the EPANET 2.2 analysis output. Technical specifications refer to pressure, speed, and demand outputs [16]. In addition to determining pump specifications, specifications for washout are also needed if needed.

The determination of criteria based on pressure is the selection of pipes that are able to withstand the load of water pressure based on the results of the compressive value on the node that has been made. The pressure on the nodes will be multiplied by 1.1 to increase the safety factor of a piping network [15]. The result is an engineering specification in the form of the nominal pressure of the pipe used.

Determining criteria based on velocity is the determination of whether the network needs to be treated at a certain location. If the speed on the network cannot meet the applicable standards even though it has been tried to be engineered, then treatment is needed with the addition of valves or washouts. So that this network performance criterion also affects the criteria for determining the location and specifications of washout. In general, the wash-out criteria will be placed at the lowest location or elevation.

2.5 Risk Analysis

Risk analysis can be done by looking at network performance [17]. Risk factors in a network are numerous, such as pipe age, history of damage to the area around the network, soil type, pipe material, pipe diameter, location of pipe accessories, and asset management planning [18]. In addition to modeling, risks can also be posed from areas around the network, such as the location of municipal waste, drainage, landslide-prone areas, and so on.

Risk analysis is carried out to estimate the likelihood that it occurs based on the results of literature studies and previous experience. The results of the risk analysis are in the form of input suggestions that can be used at the planning, development, implementation, and operational stages. The existence of a risk analysis is expected to help the owner see the potential risks that may occur and the best security measures that can be planned.

3. Results

3.1 EPANET Modeling Results

Primary data retrieval in the field produces coordinate points that are UTM coordinate types. Based on the processing of data obtained in the field, the data is inputted into the Google Earth Pro application as a database owned by drinking water companies. Coordinate and elevation data are synchronized, and information is generated in the form of images presented in Figure 2.

After input node data on EPANET 2.2, default settings and analysis are implemented to facilitate drawing and analysis according to international formulas and units. The default settings are presented in Figure 3, and the analysis settings are presented in Figure 4.

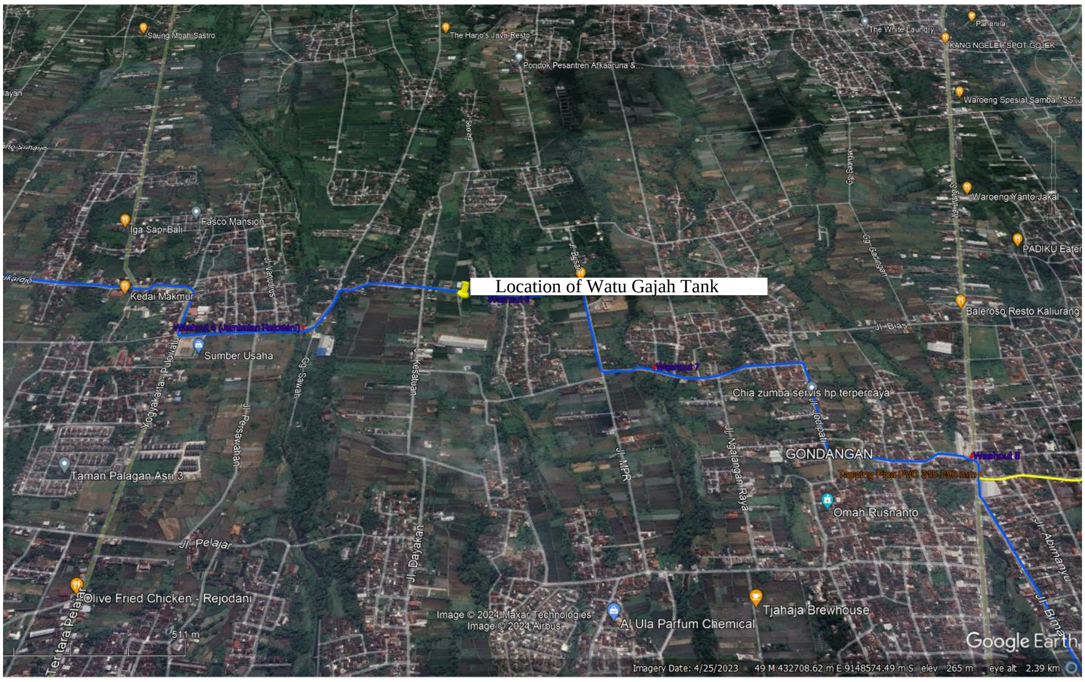

Figure 2. Coordinate point map

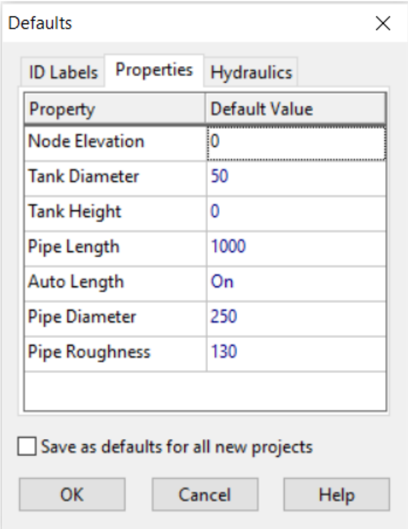

Figure 3. Setting default properties EPANET

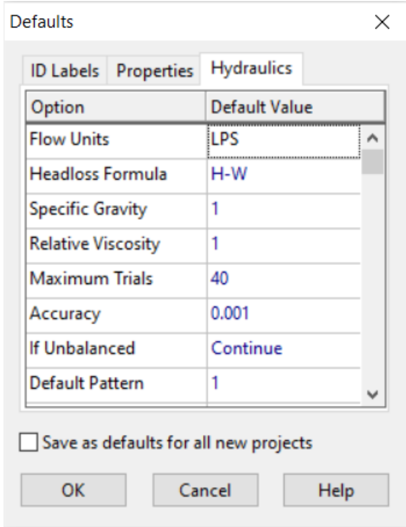

Figure 4. Setting default hydraulics EPANET

Table 2. Node coordinate

Node	X-Coord	Y-Coord	Elv. (m)	Node	X-Coord	Y-Coord	Elv. (m)
1	429331	9151939	327	32	429989	9148865	254
2	429256	9152077	324	33	429858	9148903	254
3	428988	9150527	282	34	429952	9148796	251
5	430851	9148547	249	35	430370	9148661	251
6	431272	9148237	251	37	431286	9148227	251
7	431709	9148257	251	38	431604	9148308	254
8	432757.296	9147682.148	251	39	432283	9147992	253
21	429247	9152083	324	40	432313	9147980	253
22	429203	9152010	322	41	432355	9147961	252
23	429364	9151919	327	42	432369	9147975	252
24	429477	9151767	322	43	432464	9147938	254
25	429485	9151742	321	44	432478	9147911	253
26	428852	9150178	275	45	432421	9147765	250
27	428712	9149574	258	46	432778	9147691	251
28	428741	9149533	257	47	432888	9147805	254
29	429427	9149293	255	48	432976	9147806	254
30	429697	9148963	253	49	433346	9147636	252
31	429819	9148904	254	Reservoar	429271.787	9152083.626	350

The coordinates according to the results in the field that have been synchronized are processed into a database that will be inputted into EPANET 2.2 as node coordinates. The nodes created are not only nodes in the reservoir and the planned location of the Watu Gadjah Tank, but also auxiliary nodes and nodes placed at any elevation difference high enough to allow for a drastic increase or decrease in pressure. The total node data created is 35 nodes and 1 reservoir. The coordinate data of the nodes is presented in Table 2.

Flow units indicate a change to international units, specifically liters per second (LPS), for planning purposes. Additionally, the headloss formula utilizes the Hazen-Williams (H-W) formula. The maximum number of trial analyses conducted is 40 times with an accuracy of 0.001. The initial type of pipes used was determined through discussions with drinking water companies, with specifications outlined in Table 3.

Table 3. Pipe data input

Subject	Description
Pipe type	HDPE
Pipe condition	New
Diameter (d)	315 mm
Roughness (C)	130

Transmission network planning does not use water usage patterns because the water supply data is stable at 80 l/s at the last node or location of the Watu Gadjah Tank. The analysis used a time unit of 1 hour, with the initial experiment without the use of a pump. The results of the initial depiction of the network in the EPANET 2.2 application can be seen in Figure 5. The input data of pipe elevation and length can be seen in Figure 6. The results of filling the water dam on the node are presented in Figure 7. The contour of transmission pipelines is presented in Figure 8.

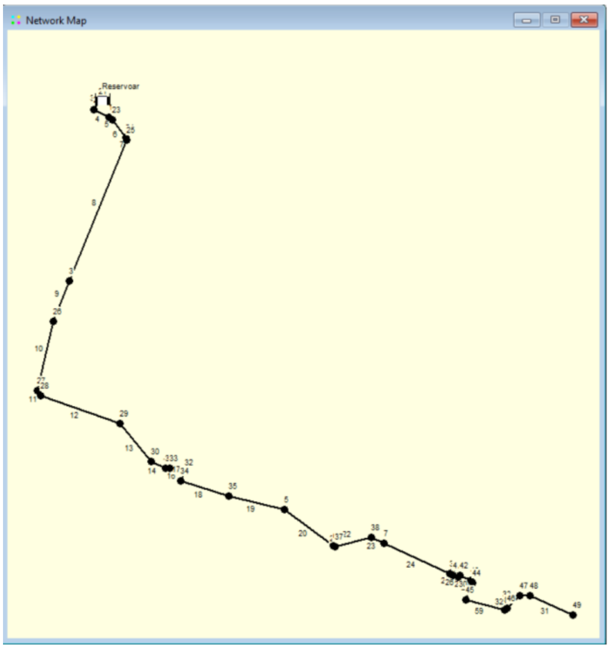

Figure 5. Transmission network modeling

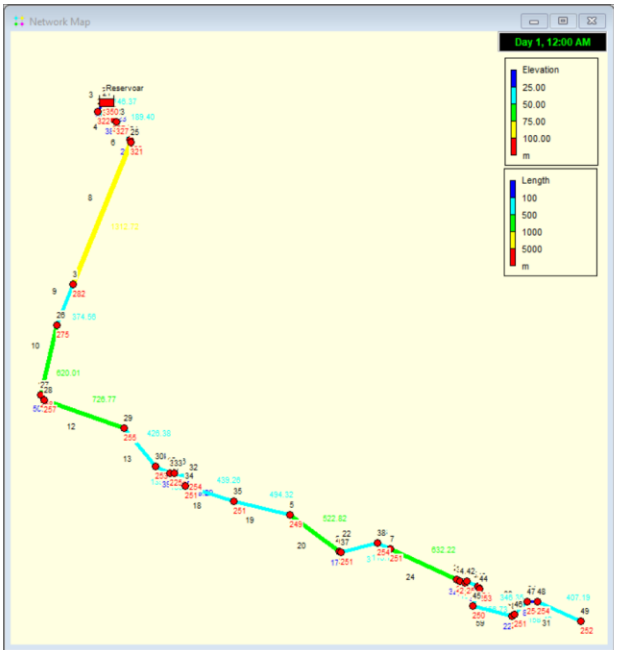

Figure 6. Elevation and pipe length modeling

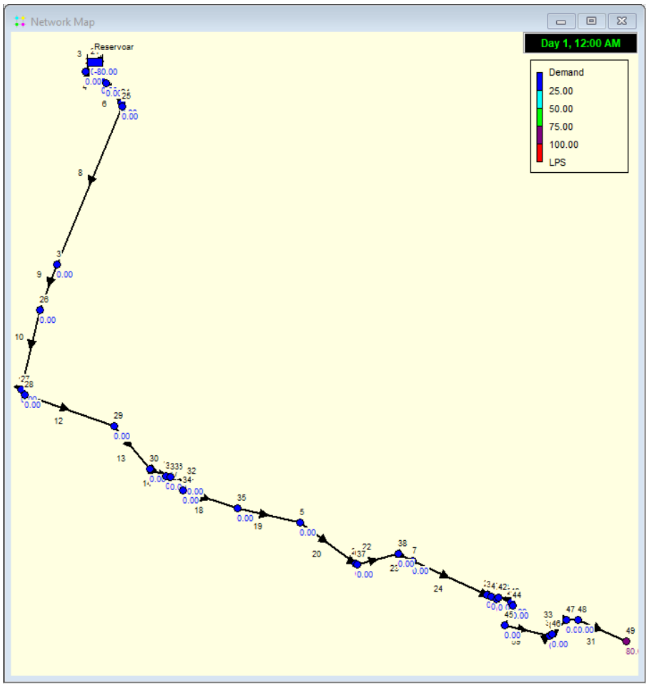

Figure 7. Water demand modelling

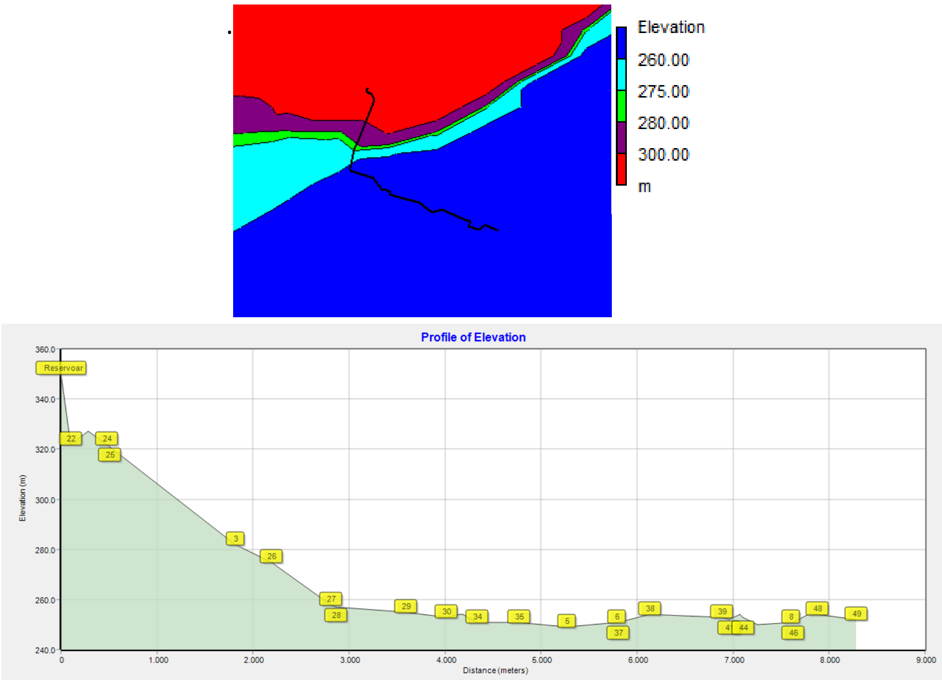

Figure 8. Contours of transmission pipelines

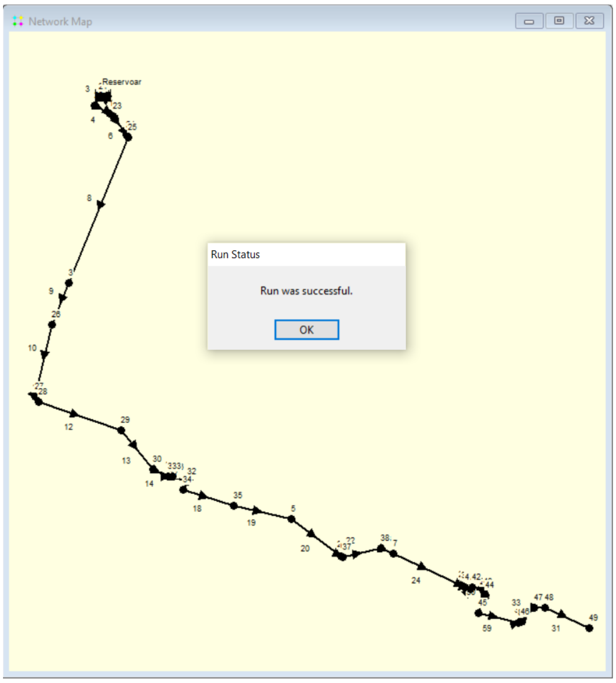

Figure 9. EPANET 2.2 analysis results

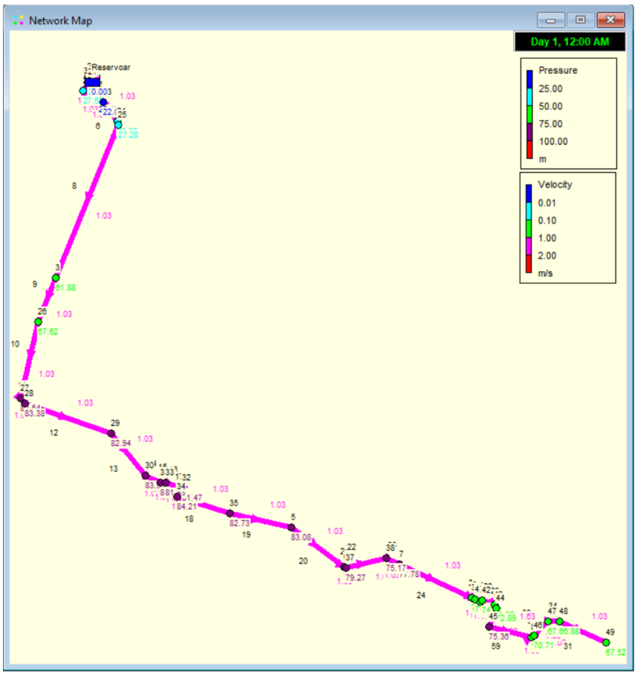

Figure 10. Results of pressure and speed performance analysis

Network modeling is followed by analysis to determine network performance. Network performance results in terms of pressure performance and velocity in the pipeline. The results of the analysis of EPANET 2.2 pressure and speed performance are presented in Figure 10.

Before carrying out analysis with EPANET 2.2, it is necessary to ensure that the data entered is correct. If there is incorrect data, then the performance analysis results cannot describe network performance correctly.

The EPANET 2.2 analysis results according to Figure 10 show the analysis status "Run was successful". This status shows that there are no erroneous analysis results and all pressure on the node has a positive value. Having positive results does not necessarily mean that network performance has met planning criteria. This status does not guarantee that network performance has been planned successfully.

Based on Figure 10, network performance without a pump has been able to drain water to the end point or location of the Watu Gadjah Tank. The analysis showed that there were some nodes that had a pressure of more than 80 m in the middle of the path and more than 50 m at the end of the network. The results of pressure performance are presented in Table 4.

Based on Table 4, pressure values ranged from 22 to 84.21 m, with the highest value being 84.21 m in jucntion 34, The pressure value in the tank is 67.52 m, and the lowest location is at the auxiliary node in the area around the reservoir. The flow velocity is between 1.03 m/s and 1.63 m/s, with the highest point in Pipe 48. The highest headloss is 10.33 m/km at Pipe 48. An illustration of pressure performance on the transmission network is presented in Figure 10.

The total modeling length of the pipe is 8,374.15 m. Based on Figure 11, the location of the highest pressure in the length range of 1,800 m to 6,000 m. If the pressure value is depicted in contour form, it can be seen in Figure 12.

Table 4. Water pressure performance

Node ID	Pressure (m)	Link ID	Velocity (m/s)	Unit headloss (m/km)	Node ID	Pressure (m)	Link ID	Velocity (m/s)	Unit headloss (m/km)
Junc 1	22.13	Pipe 1	1.03	3.35	Junc 32	81.47	Pipe 19	1.03	3.35
Junc 2	25.94	Pipe 2	1.03	3.35	Junc 33	81.93	Pipe 20	1.03	3.35
Junc 3	61.88	Pipe 3	1.03	3.35	Junc 34	84.21	Pipe 21	1.03	3.35
Junc 5	83.08	Pipe 4	1.03	3.35	Junc 35	82.73	Pipe 22	1.03	3.35
Junc 6	79.33	Pipe 5	1.03	3.35	Junc 37	79.27	Pipe 23	1.03	3.35
Junc 7	77.78	Pipe 6	1.03	3.35	Junc 38	75.17	Pipe 24	1.03	3.35
Junc 8	70.78	Pipe 7	1.03	3.35	Junc 39	73.66	Pipe 25	1.03	3.35
Junc 21	25.91	Pipe 8	1.03	3.35	Junc 40	73.55	Pipe 26	1.03	3.35
Junc 22	27.62	Pipe 9	1.03	3.35	Junc 41	74.40	Pipe 27	1.03	3.35
Junc 23	22.00	Pipe 10	1.03	3.35	Junc 42	74.33	Pipe 28	1.03	3.35
Junc 24	26.37	Pipe 11	1.03	3.35	Junc 43	71.99	Pipe 29	1.03	3.35
Junc 25	27.28	Pipe 12	1.03	3.35	Junc 44	72.89	Pipe 30	1.03	3.35
Junc 26	67.62	Pipe 13	1.03	3.35	Junc 45	75.36	Pipe 32	1.03	3.35
Junc 27	82.54	Pipe 14	1.03	3.35	Junc 46	70.71	Pipe 33	1.03	3.35
Junc 28	83.38	Pipe 15	1.03	3.35	Junc 47	67.17	Pipe 34	1.03	3.35
Junc 29	82.94	Pipe 16	1.03	3.35	Junc 48	66.88	Pipe 59	1.63	10.33
Junc 30	83.51	Pipe 17	1.03	3.35	Junc 49	67.52	Pipe 31	1.03	3.35
Junc 31	82.06	Pipe 18	1.03	3.35					

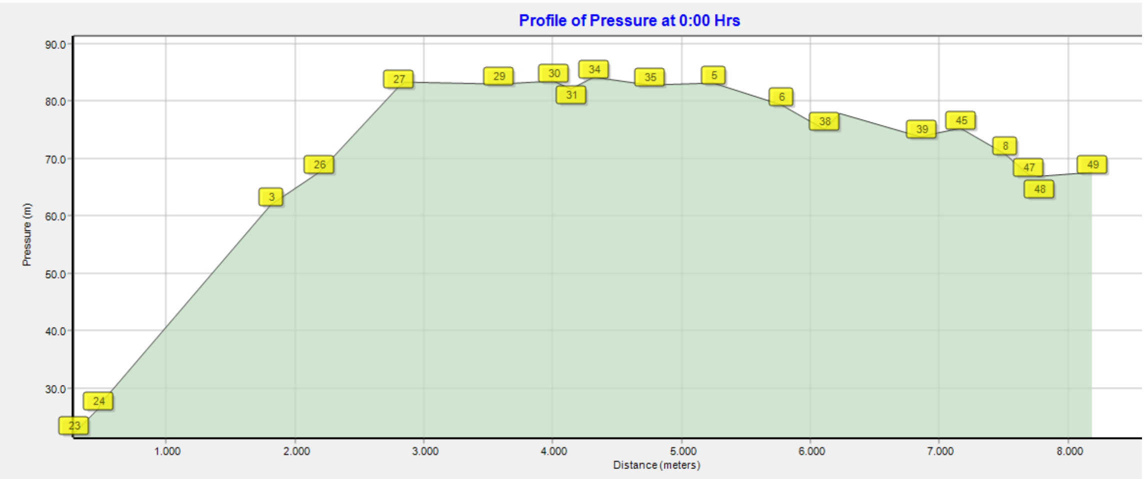

Figure 11. Upstream to downstream pressure performance graph

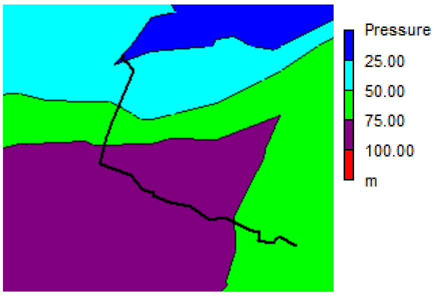

Figure 12. Water pressure contours

3.2 Conformity of Transmission Network Criteria

Based on the modeling results using the EPANET 2.2 application, it shows the value of the results of pressure analysis and flow velocity in the pipeline. Fulfillment of transmission network planning criteria in accordance with Table 1. The results of the comparison of EPANET 2.2 analysis values and criteria are presented in Table 5.

Table 5. Results of comparison of planning criteria

Parameter	Analysis results	Criterion	Status
Maximum pressure	84.21 m	10 m – 124 m	Ok
Minimum pressure	22 m	10 m – 124 m	Ok
Maximum Velocity	1.63 m/s	0.3 m/s – 6 m/s	Ok
Minimum Velocity	1.03 m/s	0.3 m/s – 6 m/s	Ok

Based on Table 5, there are 4 parameters compared, namely maximum pressure, minimum pressure, maximum speed, and minimum speed. Each paragraph is still within the range of planning criteria. The results of the planning show that the four parameters compared have met the planning criteria, so the planning is accepted and can be used.

3.3 Technical Specifications of Transmission Network

The results of the analysis using EPANET 2.2 indicate that there is no requirement for a pump in the transmission network. Water can flow naturally, utilizing the principle of gravity. Consequently, pump planning for the intended transmission network is unnecessary.

Flow velocity performance meets standards ranging from 0.3 m/s to 6 m/s. The flow naturally removes sediment or solutes present in the water. This suggests that the network does not necessitate a washout to clear sediment or solutes that could potentially accumulate within the pipeline. Hence, the precise location of the washout is not meticulously planned but will be addressed in the risk assessment sub-chapter.

The maximum pressure observed on the transmission network is 84.21 m. The fundamental planning principle employed in this process dictates that the nominal pipe pressure must exceed the pressure performance analysis conducted on the network. Technical specifications for the pipeline used in the planned transmission network dictate a nominal pressure multiplied by a factor of 1.1. Then, the acceptable pressure for the pipeline is determined to be 92.631 meters. According to catalogs provided by drinking water companies, pipes capable of withstanding pressures exceeding 92.631 meters are classified as PN-10. These results indicate that the quality of the HDPE pipe used must meet at least PN-10 standards with an inner diameter of 315 mm.

Consequently, it has been concluded that there is no need for pumps or washouts on the transmission pipeline from the Kregan Water Treatment Plant (WTP) to the Watu Gadjah Tank. The required pipe strength is 92.631 meters; therefore, HDPE PN-10 D-315 pipe is selected for cost efficiency.

Transmission Network Risk Analysis. The technical risk analysis studied is divided into several aspects, namely network hydraulic performance risk analysis, development risk, and operational risk. The risk analysis of each problem is divided into potential, consequences, and suggestions. The data used as a source of risk assessment are field survey data, regulations, and EPANET 2.2 analysis data. These three data points will be used as a study of possible planning risk analysis. It is possible that there are similarities between the three aspects studied but that they have different suggestions.

Improving Transmission Network Hydraulic Performance Aspects. The transmission network performance aspect mainly discusses network performance based on EPANET 2.2 analysis. The possibility is based on research, previous sources of problems and expert advice. The risk analysis of transmission network performance is presented in Table 6.

Aspects of Transmission Network Development. The aspect of transmission network development concerns the potential risks during development. Risk analysis is based on the results of field surveys, whose photo examples are presented in Figure 13 and Figure 14, as well as literature studies that have been carried out. Based on the data obtained, the risk analysis of aspects of transmission network development is presented in Table 7.

Table 6. Risk analysis of network hydraulic performance aspects

Potential	Result	Recommendation
Extreme pressure or altitude changes	Water hammer, pipe prone to rupture	Surveillance at vulnerable points
Pressure on large outputs	Water in the tank turbulence and erode the tank	An initial tranquilizer bath was made.
Indiscriminate tapping	Network performance changes, pressure when tapping is large	No indiscriminate tapping without planning
Considerable pressure	Because need a high-quality pipe, the cost increases.	Dividing the tank into 2 parts
High flow rate	Potensi turbulensi	Monitoring of kaporite caddie on the tank

Table 7. Risk analysis of network development aspects

Potential	Result	Recommendation
50 crossing the road.	The construction of the crossing needs to look at the situation of the condition	Construction at a certain point can be carried out by the method of Horizontal Directional Drilling
Pass through several water pollution locations (markets, entertainment locations, disposal points)	If there is seepage or there is a leaking pipe, it can be polluted	Install pipes on the other side of the road or can be given special protection at that location
Construction of crossings with internet cable pipes	If a leak occurs it can interfere with the performance of the internet cable	Built under the internet cable pipe
Passing through several points of sewage pipes	Water pollution in pipes can occur if there is a leak	Built on sewage pipes and given concrete cast stands
Passing through 4 pipe bridges	High pressure pipe, tough repair if leaked/damaged	Provided protection with cast pipes iron on pipe bridges
The path is adjacent to the old pipe	Installation and repair difficulties	Ensuring engineering of development methods

Table 8. Risk analysis of network hydraulic performance aspects

Potential	Result	Recommendation
Network repair	Network performance will stop	Built with loop model
There is a repair of leaks and dirt entering	Sediment Settling	Washed out at the valley point
Leakage	High leakage pressure	Built with loop model or added 1 more tank
Pass through several potential water pollution locations (markets, entertainment locations, disposal points)	Polluted water	Engineering and monitoring of potential pollution areas

Figure 13. Location of the new pipe bridge next to the existing pipe bridge

Figure 14. Location of existing pipelines in Sleman

Operational Aspects of Transmission Network. The operational aspect is looked at based on how the network is implemented in the field. Risk analysis that assesses if there are problems during operations. Operational issues are also very important for the company's service performance. Risks that occur during operations can affect customer satisfaction. The operational risk analysis is presented in Table 8.

The results of the risk analysis reveal several potential issues that may arise, necessitating careful consideration for the implementation of development. Additionally, proactive measures can be taken by establishing standard operating procedures for both development and operation. It is expected that the analysis will inform the implementation and planning of the Kregan WTP transmission network to the Watu Gadjah Tank..

4. Conclusion

The results of the transmission network planning from the Kregan WTP to the Watu Gadjah Tank indicate that the highest pressure value is 84.21 m. The location of the highest pressure point is on Pendowo Street, Temon, Sleman, Yogyakarta. The flow velocity ranges from 1.03 m/s to 1.63 m/s across the transmission network. All planning outcomes have satisfied the criteria set for transmission pipelines. The selected pipe type is HDPE with specifications capable of withstanding pressures up to 92,631 m, namely HDPE PN-10 pipe. According to the EPANET 2.2 analysis, pumps and washouts are unnecessary for the transmission pipelines. Based on the assessment conducted, the pipeline network is deemed feasible for construction, with several input suggestions provided from the risk analysis. The results of the risk analysis underscore the importance of reviewing and establishing standard operating procedures to ensure that planning aligns with expectations, can be effectively implemented, and enables efficient operations.

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