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Study of Physical Water Loss in Water Distribution Network using Step Test Method and Pressure Calibration

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ABSTRACT

Water distribution networks that are unoptimally operated can cause various problems so that water flows are not evenly distributed to consumers. One of the causes is the high water loss level due to leaks in the distribution pipeline system, as one of the water operators in Jakarta, Indonesia, PT. XYZ has tremendous efforts to improve the water supply system. One of them is to reduce physical water losses. The estimated percentage of physical water losses of water distribution networks in Green Garden District, West Jakarta, in April 2018 has amounted to 30%. It is still above the tolerance standard for the national water loss rate in Indonesia's Water Utilities, around 20%. It is necessary to reduce water loss to overcome this problem. After performing a step test program in the Green Garden District, it was found that there was a water loss of 84 lps in July 2018, which increased to 103.16 l/sin in May 2019 or showed an increase of 23%. Then, a pressure calibration was undertaken by placing six pressure monitoring points on the district in May 2019 using hydraulic simulation from WaterGEMS V.10. This calibration obtained the highest pressure Gap at pressure monitoring point #5 of 2.5 mH2O and the lowest pressure monitoring point #1 of 1.03 mH2O. Subsequently, leak detection measures were conducted to reduce physical water loss from January to May 2019, PT. XYZ water distribution network uses two leak detection methods, visible and invisible leak detections, which had successfully reduced its net night flows (NNFs). The leak repairs obtained 77 leak points, which consisted of 32 visible leaks and 45 invisible leaks. Total estimated leakage flows of 5.33 lps were obtained from the decrease in the net night flow, which indicates a decrease in physical water loss by 16% from January to March 2019.

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1. INTRODUCTION

The development of the City of West Jakarta triggers population growth and results in an increase in the need for drinking water. West Jakarta City, which has an area of 124.44 km2 and a population of 2,324,121 people, is spread across 8 districts and 56 villages. In December 2018 the number of customers of PT. XYZ reached 406,801 customers with a non revenue water rate (NRW) of 41.67%[1]. PT. XYZ is one of the water operators to provide drinking water services in the Jakarta Province. To improve drinking water and clean water supply services, PT. XYZ must meet the criteria in terms of quantity, quality, and continuity for their customers. One of the efforts to improve drinking water supply systems is to optimize the systems by reducing both physical and commercial water losses [2]. It is still difficult to analyze the number of physical leaks in the drinking water supply system. This is due to the occasional water loss in the piped water supply network[3]. PT. XYZ strives to reduce its water leakage rate, by monitoring its NRW level on each distribution zones and by implementing active leakage control. Estimated percentage of physical water losses of water distribution network at Green Garden District (GGD), West Jakarta, where was amounted to 30% in April 2018. This is still above the tolerance standard for the National Water Utilities Water Leakage Rate according to the Minister of Public Works Regulation in, which is approximately 20%[4].

The previous study of reducing of water loss conducted by Rita and Winardi showed that the effectiveness of using step test and leak detection using sounding method, could decrease of water loss between 14 % to 33% on their studied areas [12]. However, on the study did not reveal the improvement of the pressure on their distribution after its implementation of their leak detection program and the ideal pressure that the studied water company could achieve in order to fullfil standard drinking water pressure demanded by customers.

Based on that previous study, the objective of this study is to analyze a physical water loss reduction programs by setting several key succesful actions to measuring the magnitude of physical water loss, prioritization of leak detection, measuring pressure improvement, and to set ideal pressure that a water company can reach in order to meet a standard pressure that is demanded by its customers. The study will be very beneficial for drinking water utilities that want to reduce their high water loss issues to improve their service excelence for customers.

Non-Revenue Water (NRW) is defined as a variance between system input volume and billed authorized consumption[5]. NRW comprises unbilled authorised consumption (usually as a minor element of the water audit) and water loss(es). Meanwhile, water loss is defined as a gap between system input volume and authorised consumptions. Water Losses comprehend Commercial Losses and Physical Losses. Furthermore, Commercial Losses, or defined as apparent losses‘, are made up of unauthorised consumption and metering in accuracies. Whereas, Physical Losses, or defined as real losses‘, are the annual volumes lost through all types ofleaks, bursts and overflows on mains, service reservoirs and service connections, up to the customer metering.

In a drinking water supply system, only little amount of the water, which is produced by its water treatment plants, reaches the consumers. Usually there are leaks in several network pipe locations which cause water losses[6]. The water losses cause customer demands can not be fullfiled in terms of quantity, quality and constinuity.

Identifying physical water losses efffectively in the water distribution must be focused to detect leaks in main pipes and customer connections. Leaks in the main distribution pipe and house connections will remain leaked over a-24 hour-period and water volume lost will fluctuate as the pressure decreases over a-24 hour-period. For that reason, to compensate for the fluctuation, the water losses are calculated longer or shorter than 24 hours, and consequently the hour / day correction factor is applied. To estimate the leakage rate in the network distribution system, it is necessary to calculate Net Night Flow (NNF), which is the part of the night flow directly related to the leak. The Net Night Flow (NNF) is determined by subtracting Legitimate Night Flow (LNF) from the Minimum Night Flow (MNF)[7]. The LNF is the minimum customer consumption at the time of the MNF. The MNF is the lowest flow indistrict meter areas (or DMAs) during a 24 hour period, which generally occurs at night when most consumers are inactive. This MNF can be measured directly from data recording devices or loggers. Even though customer demand is minimal at night, many water operators still have to take into account an amount of nightly flow, which becomes customer demand at night. In a 100% metering system, the LNF is calculated by measuring the nightly hourly flow for all non-domestic demand and some (e.g. 10%) domestic meters in the DMA. The water company will then calculate the total LNF in liter per hour (l/h) and liter per second (l/s). For systems without 100% customer metering, water operators can calculate the LNF based on per capita night consumption. Based on data from other areas with 100% customer measurement, the water company can estimate night time flow rates to get the total LNF[8].

Active Leakage Control is one of the measures to control water losses. There are is a need for a very effective method of finding leaks. One method that is very well known is Step Test. The step test is a method to localize leaks to systematically reduce the size of the distribution area by closing the valve on each section of the pipe in turn, while simultaneously recording the change in flow rate on the meter[9]. A large decrease in flow rate indicates leak in a section of pipe or sub that was just closed. This method is faster and more effective in determining priority areas to detect for leakage points. The step test is carried out at the minimum flow period at night, where the customers are inactive and don't consume water. The step test is implemented by installing a portable flow meter (ultrasonic flow meter) in the a sub area of network distributions or district meter area (DMA) inlet valve which will record the flow during the step test is undertaken. Then systematic closing of the valve in each sub area is carried out and all reduced flow is recorded in a logger or flow meter. Disproportionate decrease in flow determines the sub area or a pipe segment that have suspected leaks.

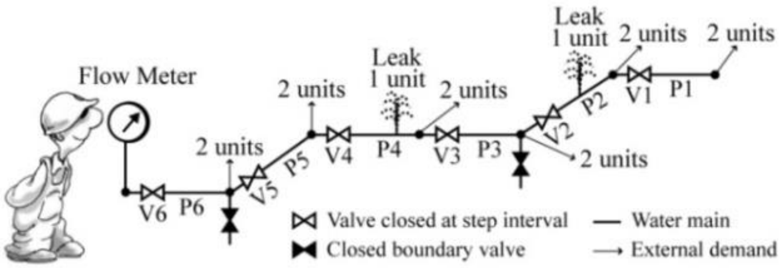

Figure 1. Scheme of Step Test

The step area must use a scheme of a tree-like structure with only single water source that is supplied through a single meter and must not contain any loops, as depicted in Figure 1. After localizing leaks using the step test program, Ground microphones, Leak Correlators or Noise Loggers can be used to pinpoint the leak locations along the pipes, which leak repairs are able to be conducted. The sequences of step tests and leak detections and repairs are repeated until minimum leakage level is acceptable in those sub water distribution zones or pipe segments [8], [10]. Pressure in network pipes is very important to be taken into account a water distribution system. If a network is designed properly, a network of interconnected pipelines, reservoirs, pumps and control valves will provide good water pressure, supply and quality throughout the system. If the network distribution is designed incorrectly, some areas will have low pressure, cause adverse affects to the Fire Fighting Service, and even pose a health risk to customers[11].

WaterGEMS V.10 software is used as a tool to design and analyze pressure and flow in water distribution systems. The software has been used by many water companies as a tool to operate the distribution system efficiently. WaterGEMS can be a stand-alone program, or integrated to AutoCAD and geographic information systems (GIS)[11]. In the software, the major and minor headlosses are calculted, as follows:

$$H_f = \frac{10{,}694 \ x \ Q^{1{,}85} \ x \ L}{C^{1{,}85} x \ D^{4{,}85}} \qquad \text{.................................... (1)}$$

where :
Hf = Hazen-Williams major frictional headloss (m)
C = Hazen-williams roughness constant
L = length of pipe (m)
Q = water flow (liter per second)
D = diameter (m)

$$H_l = K\frac{V^2}{2g} \qquad \text{.................................... (2)}$$

where :
Hf = minor headloss (m)
K = minor headloss coefisient
V = velocity (m/s)
g = acceleration due to gravity (m/s^2)

2. RESEARCH METHODS

The initial step of the research methodology was to conduct a net night flow (NNF) analysis using MNF data in April - June 2018 to determine the level of water loss in the Green Garden District (GGD). Since the water distribution networks in GGD are very large, then district was divided into 2 areas (Area 1 and Area 2) in order to easily set a priority area in detection the leakages. Subsequently, a step test program was conducted on those areas to specify on which area of the district that had the largest water loss. The step test was carried out at the minimum flow period between 24.00 - 02.00, where customers were inactive and did not consume water. The step test scenario of closing valves is depicted in Figure 2.

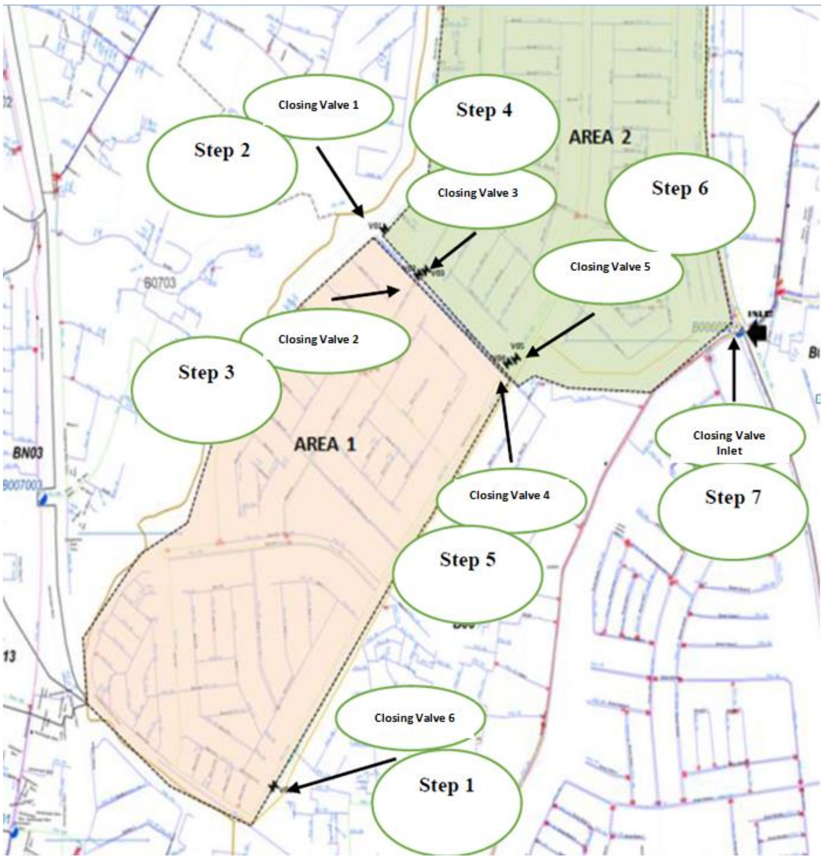

Figure 2. Step Test Scenario of Closing Valves.

The procedure of step test in this study were as follows:

a. Preparation works : Prepared the flowmeter at the inlet valve of the areas in a good condition and calculated number of House Connections (HC) in Area 1 and Area 2
b. Flowed the water (Q)
c. Closed Valves in area 1 and 2 and recorded the number shown on the flowmeter
d. Calculated water loss
e. Calculated rasio water loss to the numbers of house connections ($\Delta Q/\sum HC$)
f. Classified types of water loss based on $\Delta Q/\sum HC$ to prioritize the area for leak detection.

Classifications of types of water loss in a certain area, are as follows:

a. Low water loss if ΔQ/∑HC = 0,001 - 0,0049 liter per second (lps)
b. Middle water loss if ΔQ/∑HC = 0,0050 - 0,019 lps
c. High water loss if ΔQ/∑HC > 0,0020 lps

The higher ratio (ΔQ/∑HC) in an area, the more priority for water loss reduction programs. Next, the identified area that had the largest water loss would be prioritized for the execution the leak detection and repair program in order to reduce its water loss level. There were 2 leak detection methods used to detect visible and invisible leaks. The visible leaks were searched by a group of leak surveyors along the intended network distribution, while the invisble leaks were detected by leak detection using helium gas. After the leaks were found and repaired, 7 (seven) monitoring points were placed at several locations in the identified zone. The purpose of setting of these monitoring points was to measure the changes of flow and pressure in the network after the leak detection and repair had been carried out. By doing so, the decrease in water loss and the improvement of the pressure in the network can be conducted.

At the same time, a hydraulic simulation was performed to obtain ideal pressures in the distribution network using WaterGEMS. Furthermore, a pressure calibration was conducted with an objective to compare the results of the pressure measurement on network (after the repaired program) and the ideal pressure from WaterGEMS. By calculating the pressure gap from the calibration, we are able to analyze the existence of NRW that remained on particular pipe networks. The subsequent leak detection will be required to be executed to reduce the gap between pressure theoritical (shown on WaterGEMS) and pressure on-field. The smaller of the pressure gap is the better.

3. RESULTS AND DISCUSSION

Monitoring of the Minimum Night Flow (MNF) was conducted at interval of 24.00 to 02.00 which was carried out in June 2018. The results of monitoring for the MNF in May 2018 can be seen in Table 1.

Table 1. Average MNF for Period of April to June 2018

Date	April	May	June
	Flow (L/s)	Flow (L/s)	Flow (L/s)
1	69,27	71,62	73,98
2	70,38	70,98	74,18
3	69,27	72,56	74,58
4	72,33	71,49	74,40
5	71,33	71,47	75,42
6	70,07	72,31	77,20
7	70,66	70,98	81,64
8	66,89	71,42	80,96
9	67,69	74,60	81,20
10	68,47	65,31	80,02
11	67,39	72,87	79,04
12	74,45	73,20	80,45
13	72,60	71,67	79,78
14	73,29	72,09	80,15
15	70,38	73,84	78,49

Date	April	May	June
	Flow (L/s)	Flow (L/s)	Flow (L/s)
16	70,96	72,40	78,09
17	70,44	73,53	75,35
18	70,80	76,29	77,91
19	72,24	82,60	75,58
20	71,82	80,51	78,16
21	73,71	80,20	78,85
22	74,56	82,80	78,29
23	72,40	80,76	76,49
24	71,44	74,27	78,13
25	72,78	73,11	76,29
26	72,44	74,47	76,02
27	71,27	75,44	72,51
28	71,09	74,18	73,94
29	73,47	74,69	75,07
30	72,33	75,13	75,36
31		74,78	
average	71,21	74,24	77,25
LNF	50	50	50
NNF	21,21	24,24	27,25

Based on these data, the average flows at night in April, May, June were respectively 71.21 l/s, 74,24 l/s and 77,25 l/s. The MNF values exceeded the LNF of 50 l/s. There was a Gap of MNF of 21.21 l/s or 30% higher than the LNF. Thus, the leakage rates (NNFs) in April, May, June were 21,21 l/s, 24,24 l/s, dan 27,25 l/s.

To figure out the area that had the greatest water loss, a step test program was carried out in July 2018. The step test was conducted to determine the location of the pipe segment that had the highest water loss. The step test scenario and results can be seen in Table 2.

Table 2. The step test results conducted in July 2018

Step	Valve Closings							Hours	Q	ΔQ	∑HC	ΔQ/∑HC	Types of Water Loss
	V6	V1	V2	V3	V4	V5	V Inlet		(lps)	(lps)	(unit)		
Start	O	O	O	O	O	O	O	00.00	80	-		-	-
Step 1 (Area 1)	C	O	O	O	O	O	O	00.19	72	8	1336	0,0060	Low
Step 2 (Area 1)	C	C	O	O	O	O	O	00.50	70	2		0,0015	Low
Step 3 (Area 1)	C	C	C	O	O	O	O	00.53	72	-2		-0,0015	Low
Step 4 (Area 1)	C	C	C	C	O	O	O	00.59	72	0		0,0000	Low
Step 5 (Area 1)	C	C	C	C	C	O	O	01.33	71	1		0,0007	Low
Step 6 (Area 1)	C	C	C	C	C	C	O	01.40	68	3		0,0022	Low
Step Inlet (Area 2)	O	O	O	O	O	O	O		0	68	3486	0,0195	High
Finish										80	4822		

O = Opened; C = Closed

The process of detection of leaks in the study used 2 methods, namely Visible and Invisible Leak Detections. The visible leak detection is a leak detection method, that is used to find visible leaks by tracing the pipe networks by a group of Leak Surveyors. Meanwhile, the invisible leak detection is a leak detection method that is used to find invisible leak points by injecting helium gas into piping distribution networks and detecting the networks using helium detectors. After the leaks were found, the repair process were conducted, where by replacing damaged accessories or cutting the leaking the pipe segment, which depended on the types of leaks. In addition, the reinstatement process was carried out, as the last activity to restore the excavation back to the initial trace conditions.

The leakage flow estimation was carried out to calculate the leakage flow that occured, which was carried out by two methods, namely the measuring method with a measuring cup and a measuring method using excavated pit volume. The method of measuring excavated pit volume was carried out if the method of measuring with a measuring cup in the field could not be used due to small dimension of the excavated pit. The method of measuring the volume of excavation used the excavation dimension (in m^3 or dm^3) divided by the time to reach the specified depth (10 cm). Doing so could produce the values of the leakage flows. The numbers and the flows of visible and invisible leaks can be seen in Table 3a and 3b.

Table 3a. Number of Visible Leaks in GGD

Visible Leaks				
Months in 2019	Number of Leaks in House Connections	Number of Leaks in Distribution Networks	Total Number of Leaks	Estimated Leak Flow (l/s)
January	11	6	17	1,4
February	8	1	9	0,08
March	2	4	6	0,14
April	10	0	10	0,74
May	1	2	3	0,17
Total	32	12	45	2,53

Table 3b. Number of Invisible Leaks in GGD

Invisible Leaks				
Months in 2019	Number of Leaks in House Connections	Number of Leaks in Distribution Networks	Total Number of Leaks	Estimated Leak Flow (l/s)
January	6	9	15	0,4
February	2	1	3	2,02
March	0	0	0	0
April	4	6	10	0,32
May	3	1	4	0,06
Total	15	17	32	2,8

The second step test was held in June 2019 and aimed to observe for a supply improvement from leak detection and repair that had been carried out from January to May 2019. The results of the Step Test can be seen in Table 4. The result of the second step test showed a water loss of 103.16 l/s, which was greater than the water loss of 84 l/s in the first step test conducted in July 2018. Thus, there was an increase in water losses of 19.16 l/s or 23%, compared to the former.

Table 4. The step test results conducted in June 2019

Step	Valve Closings							Hours	Q	ΔQ	∑HC	ΔQ/∑HC	Types of Water Loss
	V6	V1	V2	V3	V4	V5	V Inlet		(lps)	(lps)	(unit)		
Start	O	O	O	O	O	O	O	01.31	78,66	-		-	-
Step 1 (Area 1)	C	O	O	O	O	O	O	01.31	78,66	0	1336	0,0000	Low
Step 2 (Area 1)	C	C	O	O	O	O	O	01.37	77,15	1,51		0,0011	Low
Step 3 (Area 1)	C	C	C	O	O	O	O	01.44	77,14	0,01		0,0000	Low
Step 4 (Area 1)	C	C	C	C	O	O	O	01.53	77,07	0,07		0,0001	Low
Step 5 (Area 1)	C	C	C	C	C	O	O	02.14	89,32	-12,25		-0,0092	Low
Step 6 (Area 1)	C	C	C	C	C	C	O	02.22	88,64	0,68		0,0005	Low
Step Inlet (Area 2)	O	O	O	O	O	O	O		0	88,64	3486	0,0663	High
Finish										78,66	4822		

O = Opened; C = Closed

The second MNF monitoring was carried out in early January to June 2019. The MNF monitoring aimed to observe a decrease of the MNF after the implementation of leak detection and repair measures. The MNF daily monitoring during January to May 2019 can be seen in table 5.

Table 5. Average MNF from January to May 2019

Date	January	February	March	April	May
	Flow (L/s)	Flow (L/s)	Flow (L/s)	Flow (L/s)	Flow (L/s)
1	68,40	75,38	62,91	50,49	73,38
2	69,71	79,87	47,47	44,53	72,95
3	39,61	81,60	68,13	18,92	73,71
4	79,89	75,24	55,42	59,11	73,85
5	79,89	82,47	55,13	40,97	71,62
6	80,24	66,73	66,29	40,97	68,25
7	78,82	66,73	64,36	57,31	69,69
8	79,98	66,73	54,24	35,51	69,95
9	65,22	62,49	57,31	57,31	72,29
10	66,36	59,84	51,62	35,51	69,73
11	70,09	58,73	58,33	69,96	67,60
12	80,09	69,58	57,31	73,71	66,47
13	73,89	70,80	57,31	70,44	67,67
14	56,07	69,96	56,27	69,20	67,49
15	66,31	60,02	67,27	71,73	67,56
16	79,98	67,29	63,09	71,56	66,25
17	68,38	72,27	51,53	68,42	67,11
18	69,04	68,00	63,31	69,20	72,22
19	76,47	72,42	63,73	68,91	70,65
20	75,40	64,98	52,13	67,62	69,42
21	79,82	62,38	68,42	67,53	68,56
22	79,87	57,51	54,13	68,29	70,11
23	67,71	66,07	54,51	67,84	71,38
24	62,11	55,98	55,24	68,67	69,93
25	75,47	52,47	54,04	66,76	81,00
26	76,69	65,93	50,22	66,98	71,67
27	80,80	64,96	58,09	68,53	72,67
28	63,09	66,87	58,04	66,91	74,33
29	67,13		64,36	67,38	82,33
30	79,64		52,64	67,80	82,34
31	71,00		58,33		81,33
Average	71,85	67,26	58,10	60,60	71,73

From the results of the average MNF value in Table 5, the Net Night Flow was calculated which can be seen in Table 6.

Table 6. The Results of Net Night Flows in 2019

Month	Jan	Feb	Mar	Apr	May
Flow (l/s)	97,53	96,62	95,81	95,43	94,68
MNF(l/s)	71,85	67,26	58,1	60,6	71,73
LNF(l/s)	50	50	50	50	50
NNF(l/s)	21,85	17,26	8,1	10,6	21,73
%	30%	26%	14%	17%	30%

From the result of the NNF in January was 21.85 l/s or 30% and in March 2019 was 8.1 l/s or 14%. There was a decrease of the physical water loss level within 3 months after the leak detection and repair process was carried out, amounting to 13.75 l/s or 16% decrease. This had an improving impact on its supply in the distribution network, in the form of flow decrease and pressure increase. However, in May 2019, there was a NNF increase to 21.73 l/s or 30%. This showed that over time, the pressure increase could trigger new leaks, in the form of leaks that were small and could not be detected, becoming larger ones. Thus, a leak detection program must be carried out again or periodically to maintain the NRW level of a distribution area on an acceptable level.

Subsequently, the distribution pipe network was analyzed using WaterGEMS, where the application was run by including on several aspects, such as: flow, pressure at the junction (node) and pipe. This hydraulic simulation used a Hazen-William equation with the pipe coefficient formula that is adjusted to the pipe material used in this network. The pipe coefficients that were used for High Density Poly Ethylene (HDPE) pipe is 130, Poly Vinyl Chloride (PVC) uses a coefficient of 120, and Ductile Cast Iron Pipe (DCI) uses a coefficient of 110 according to applicable standards. The flow simulation in this network used a flow pattern which was assumed to be 24 hours in which at certain hours water consumption has increased, according to a predetermined flow pattern. The flow pattern was used to determine the time of drop-point and peak-point junction as well as pipes in the pipeline network against the above aspects. The steps were as follows:

1. To export distribution pipeline network map from ArcGIS format into WaterGEMS V.10 software
2. To assign water demands
3. To assign elevation data at each junction
4. To assign pipe length data
5. To assign a pipe roughness data
6. To assign pipe diameter

The simulation results of running model using WaterGEMS can be seen in Figure 3. A comparison of trends in production and existing pressure conditions from the WaterGEMS simulation can be seen in Figure 4.

This trend showed a gap between the flow that occurs in the existing condition on field and the ideal flow, using the Hazen-Williams formula, obtained from hydraulic simulation using WaterGEMS. The average flow displayed in WaterGEMS was 62.46 l/s. While the average flow in the existing conditions was 104.15 l/s, where there was a gap of 41.69 l/s.

Figure 3. Result of Running Simulation using WaterGEMS

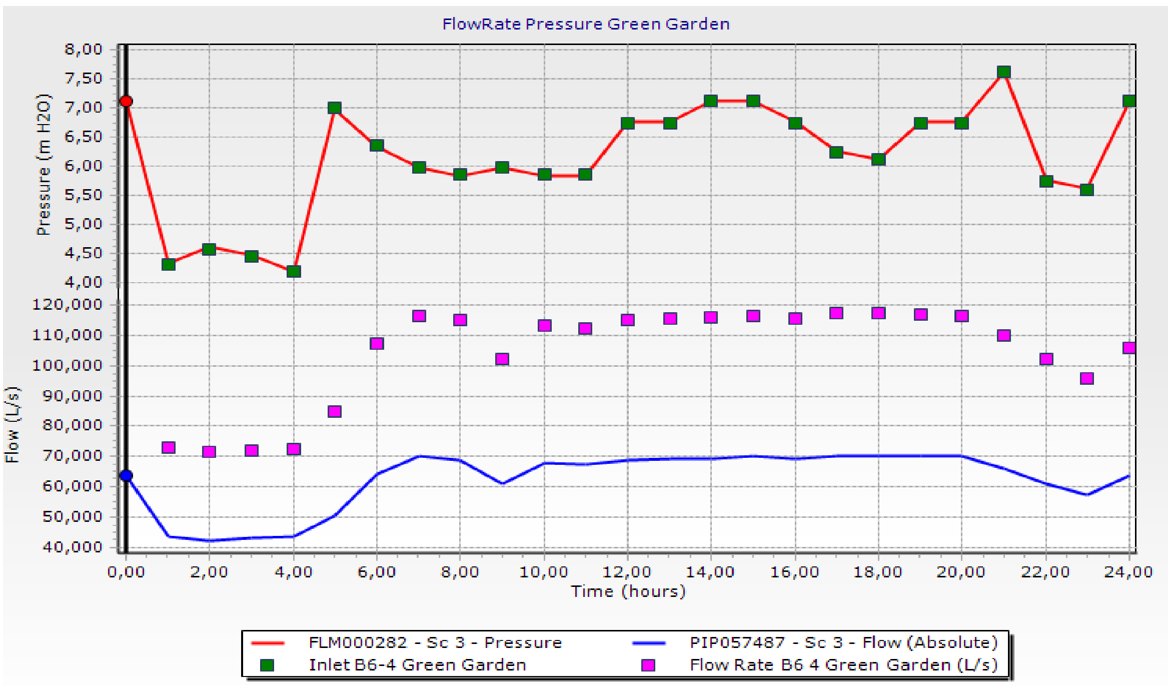

Figure 4. Flow and Inlet Pressure in Existing Conditions and Running Model of WaterGEMS

This showed that to produce a pressure of 6.12 mH20 at the network inlet, the water operator (PT. XYZ) flowed water of 104.15 l/s into the network, which should only require 62.46 l/s. This condition indicated an existence of water loss in the network.

Pressure distribution calibration was done on the distribution network by setting insertion loggers in pressure monitoring chambers uses which could measure pressures and flows in the required time intervals. The loggers were placed in each chamber with measurements for 24 hours. The purpose of this calibration process was to compare the results of the pressure in WaterGEMS and pressure data from the field, so that it can be identified which pipe segments have the highest pressure drops. The field pressure monitoring chambers were set on the in the network which had a high water loss. There were 7 pressure monitoring chambers in the distribution netwoks. The pressure monitoring points were set in the form of Junctions in WaterGEMS, which can be seen in Figure 5.

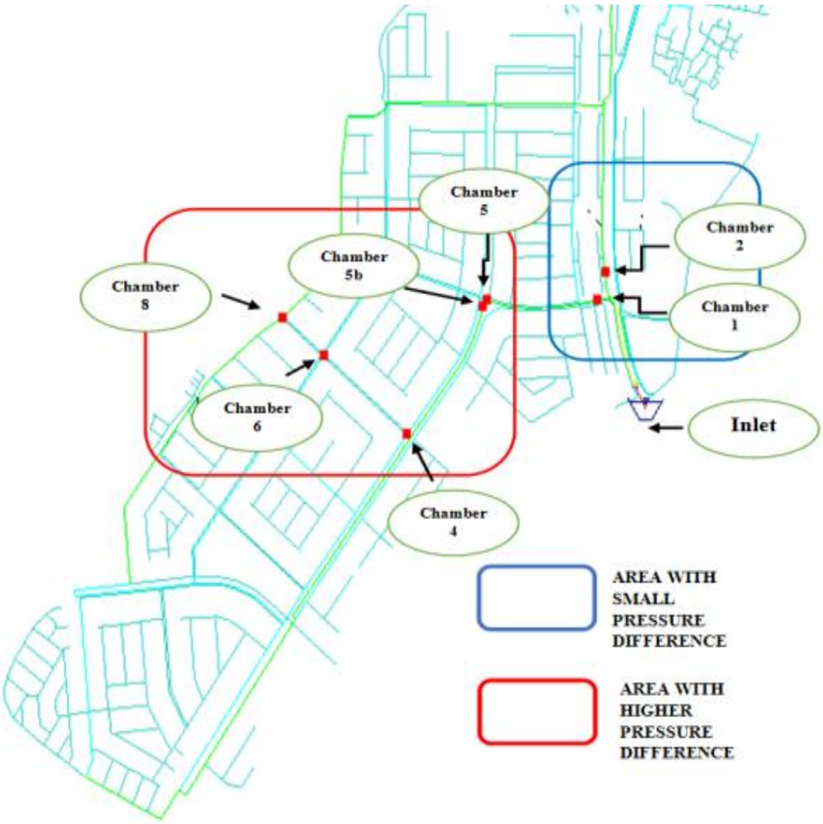

Figure 5. Placement of Pressure Monitoring Inside 7 chambers

Measuring pressure on-field was conducted in May 2019, with the result of pressure data from Chamber 1 can be seen in table 7.

Table 7. Calibration Data of Chamber 1

Hour	Pressure (mH2O)	HGL (mH2O)	Pressure WaterGEMS (mH2O)
01.00	3,7	4,60	4,10
02.00	3,9	4,80	4,40
03.00	5,2	6,10	4,25
04.00	4,2	5,10	3,95
05.00	3,9	4,80	6,63

06.00	4,7	5,60	5,71
07.00	4,9	5,80	5,23
08.00	4,9	5,80	5,11
09.00	5,3	6,20	5,42
10.00	5,1	6,00	5,13
11.00	4,7	5,60	5,14
12.00	4,8	5,70	6,04
13.00	5	5,90	6,03
14.00	5,1	6,00	6,38
15.00	5,2	6,10	6,37
16.00	4,7	5,60	6,03
17.00	4,7	5,60	5,51
18.00	4,9	5,80	5,37
19.00	3,9	4,80	6,01
20.00	4	4,90	6,01
21.00	4	4,90	6,96
22.00	3,8	4,70	5,21
23.00	4	4,90	5,14
00.00	3,3	4,20	6,51
Average	4,50	5,40	5,53
Elevation	0,90	5,40	

Table 7 shows the results of the average pressure at Chamber 1 of 4.50 mH20 with an elevation of 0.9 m. Then hydraulic gradient line (HGL) at the inlet can be calculated at 01.00 by formulated as follows:

HGL = Pressure + Elevation = 3.7 + 0.9 = 4.6 mH2O

Analysis of the pressure gap between the average pressure on WaterGEMS (or ideal pressure) and pressure measured on-field showed that the pressure gap was 1.03 mH20. It was obtained from the deduction of 5.53 mH20 (pressure ideal) and 4,5 mH2O (pressure on-filed). It explained that the re-detection of leakages had be conducted on field (network distribution) until the pressure on distribution network reached closer to the ideal pressure. The closer is the better, although the efficiency of operational expenditures had to be taken into consideration by the water company.

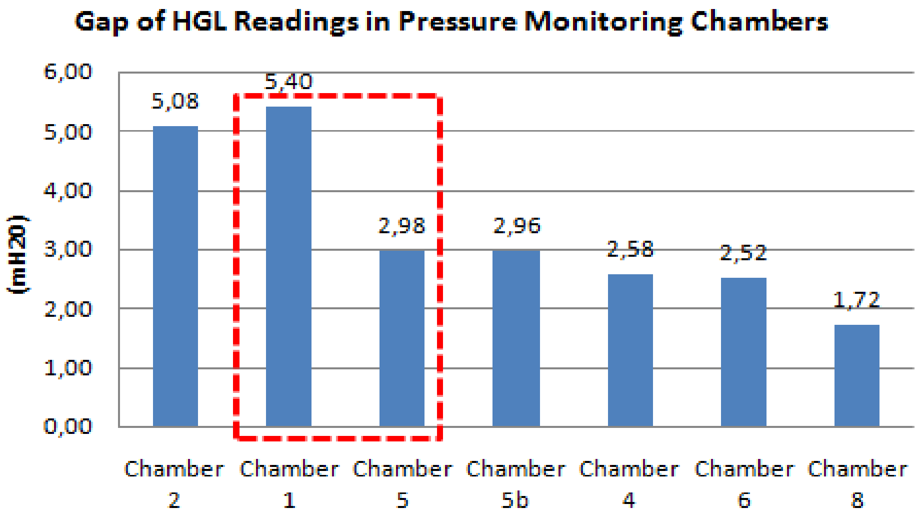

Figure 6. Gap of Pressure during Calibration

Figure 6 shows the result of the pressure gap between the pressures resulted only from the pressures from field measurements on the monitoring chambers. Areas with small water losses occured in chamber 1 and chamber 2, where the HGL gap was relatively small 1 - 1.5 mH20. Chamber 1 and chamber 2 are laid on the same pipe segment. The highest water losses began to appear between chamber 1 and chamber 5 because the HGL gap was more than 2.5 mH2O (red dashed line). Chamber 1, 5, 5b and 4 are placed on the same pipe segment, which are indicated by a blue line, as depicted in Figure 7.

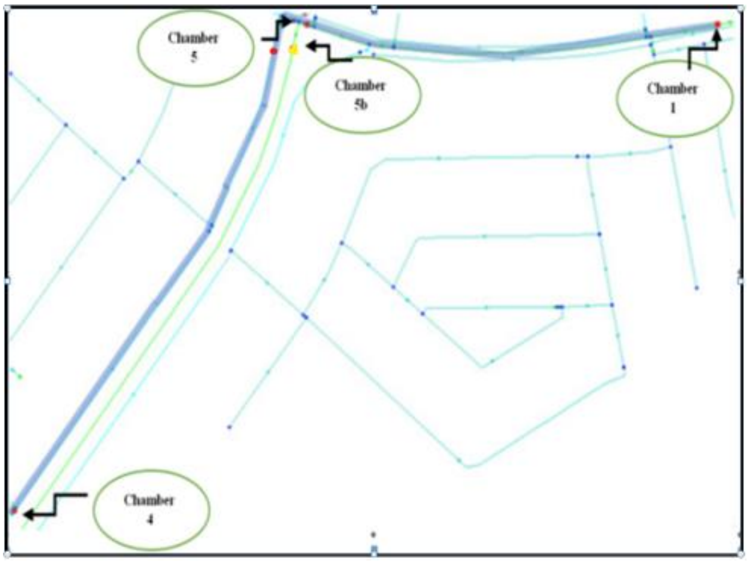

Figure 7. Location of Chamber 1, 4, 5, and 5b

Figure 7 shows the pipe segment from chamber 1 to chamber 5 indicated the highest water loss. This pipe segment is recommended to have further leak detection programs until all leaks that causes the pressure drop, will be found and repaired. Basically, all leak detection programs are conducted, until the pressure on-field reaches the ideal pressure.

4. CONCLUSION

Reducing physical water loss on distribution network can be optimaly done, started by analyzing the net night flow to determine the magnitude of water loss, conducting step test programs for localizing the area with highest water loss as the priority area, executing leak detection measures on the priority area, measuring pressure on distribution network before and after the implementation of leak detection, and doing pressure calibration. After leak detection conducted, the NNF values showed a decrease of water loss level around 16% (13,75 l/s) over the first-3 months, but the values increased by 30% (21,73 l/s) from April to May, which indicated the occurence of new leaks due to pressure increase after leak repairs. Meanwhile, the pressure gap. The pressure gap between the ideal pressure and pressure in distribution network was 1.03 mH2O, which indicates a room for re-implementation of leak detection, to improve the pressure on-field reaches to the ideal pressure. Whereas, the pressure gap among the pressure readings in monitoring points, which amounted to 2,5 mH2O, could be an indicator of a big leak, which could be detected in the next leak detection program. These methods as described the study are very beneficial for drinking water utilities or drinking water munipalities that are struggling in reducing their high water loss issues.

5. FURTHER STUDY

It is advised that a further leak detection program and network investigation be continued in the pipe segment from chamber 1 to chamber 5 to until the gap between pressure on-field and the ideal pressure become very small. Furthermore, it is recommended to have further research to observe pressure gap between pressure ideal and current piping network quality, as a higher headloss can be caused by condition of its piping network quality. Other additional parameters are the ones from commercial water loss, such as Illegal Connection and illegal use as well as inaccurate meters in the Green Garden District because these parameters are also taken into consideration in NRW calculation.

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