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Model base optimized solution to eliminate "no water" complaint at the water supply distribution network of Ampara water supply scheme

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Abstract
The pipe-borne drinking water supply systems have been in operation since the colonial period in Sri Lanka. After the Independence, and with the involvement of the Galoya Development Board, the water supply system was developed covering the township of Ampara district also, and it was later taken over by National Water Supply & Drainage Board. The distribution system was extended from time to time in surrounding areas in an ad-hoc manner. No proper hydraulic model was available to identify the sizes of pipes and storage capacity required to satisfy the demand without any "no water" complaint. Therefore, this research was undertaken to identify whether the existing system is adequate to supply water to satisfy the required demand in the Ampara region. Moreover, this study also covered the capacity of storage tanks and sizes of pipelines required to satisfy the demand after ten years and twenty years of period. In this research, Existing pipe networks of the Ampara region were drawn in Arc-GIS and WaterGem model was developed to identify the pipe sizes and storage capacity of tanks. The results show that, since the existing elevated storage tanks are not enough for direct supply throughout the day, the network bypassed the pumping pipeline. Moreover, storage tanks were used as balancing tanks while introducing necessary controls. Furthermore, to maintain limited residual pressure and required flow in the system, a variable frequency drive pumping system was introduced at the pumping station and inconsistency in the network model has been improved while introducing necessary changes for physical components. The proposed physical changes can be documented for construction relevant to this field in the future.

Keywords: Drinking water supply, Dynamic hydraulic model, Pipelines, Storage tank.

1 Introduction

The drinking water supply network significantly impacts the quality of human life and health. High quality, well maintained and managed water supply scheme is a core component of infrastructure for an urban area. The existing Ampara water supply scheme was constructed & commissioned by the Galoya Development Board before the 1970s, having the Ampara Irrigation tank as the source and the treatment with sand filters. Initially, the water supply covered only the township of Ampara region. Later, the scheme was taken over by Ampara Municipal Council and thereafter National Water Supply & Drainage Board (NWSDB). The distribution network was extended to the nearby villages from time to time due to high public demand. However, the pipeline extension was not properly designed to cater to the required amount of water as there is no properly developed hydraulic model to calculate the required capacity of storage and sizes of pipes. The scheme was augmented in the year 2006 with the construction of a new water treatment plant at Konduwatuwana called kfw Water Treatment Plant (WTP). Moreover, the larger length of pipes in the distribution system was replaced with a larger diameter of pipe network, and the surrounding area was further extended with a pipe network.

The infrastructure facilities of the township and suburbs had also been developed rapidly in parallel with the national development plan. On the other hand, it had caused drastically

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increased drinking water demand. Therefore, NWSDB is facing difficulties to cater to the present demand due to the inadequate capacity of the storage system, improper pipe network, and uncontrollable direct pumping system.

The hydraulic model of the water distribution network is an efficient and reliable decision-making tool for the rehabilitation of the existing water supply network. In hydraulic models, equations are used to calculate hydraulic parameters such as flow rate, velocity, pressure head, etc. at any point of the network. Moreover, the obtained results can be displayed in tabular and graphical forms for evaluation by the users. The success of hydraulic model predictions depends on the accurate input parameters, namely diameter, demand, connectivity, etc.

The objective of this study is to propose an optimized water supply network improvement to eliminate "no water" complaints for current demand and future demand (10 years & 20 years) for reliable operation and maintenance of the Ampara Water Supply Scheme.

2 Materials and Methods

2.1 Study area

The study area of the research is the distribution networks of the Ampara water supply scheme. This water supply scheme consists of a large number of pipe connectivities with the shortest length and a huge number of network elements. The topography is moderately changing over the study area and elevation varies between 20 m to 51 m above the Mean Sea Level (MSL). This water supply scheme supplies water to different types of consumers, namely domestic, commercial, industrial, institutions, and religious places. The schematic diagram shown in Figure 1 illustrates the complexity of the network connectivity of the system. Although, most of pipes in the water supply network are Poly Vinyl Chlorite (uPVC), Ductile Iron (DI) pipes are also used in some places. The diameter of both uPVC and DI pipes varies from 63 mm to 350 mm.

Field visits were arranged to identify the pipe networks and their diameter, junction connectivity, and valve locations, which are depicted in Figure 2. Moreover, connectivity of pipes was also verified by referring to available sketches, data collected in the field, and experience shared by retired staff. Furthermore, nodal elevations were measured using GPS and a population survey was carried out with the help of Google Earth maps.

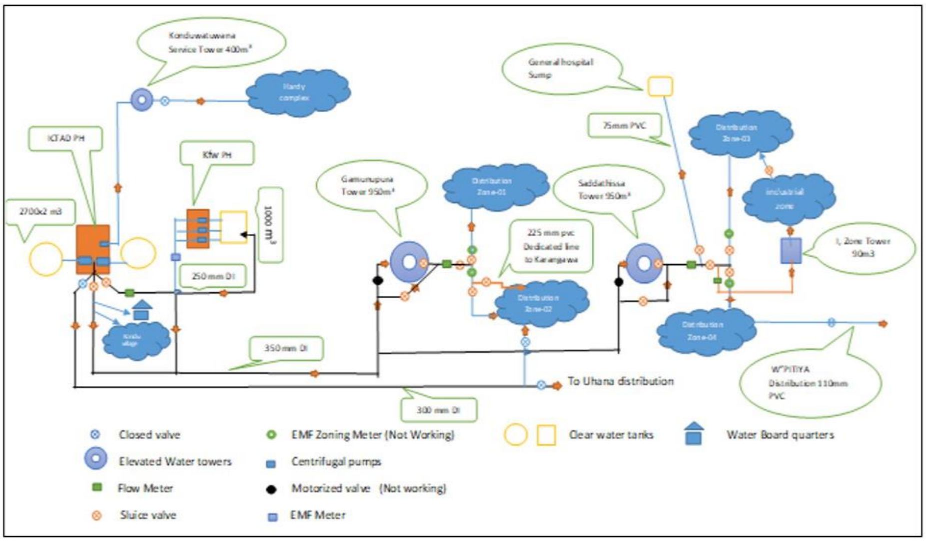


Figure 1. A schematic diagram shows the current arrangement of the Ampara Water Supply scheme

Figure 2. Existing water supply network with pipe diameter and valve types

2.2 Demand calculation

Water demand is the driving force behind the hydraulic dynamics occurring in hydraulic model and use of water was spatially distributed as demands are assigned to model nodes. The system water demands were distributed to model nodes or junctions using the guidance of NWSDB Manual. The estimated average daily demands were calculated using NWSDB commercial division data, and the NWSDB manual data. The total demand along a main was split into half and added to each end node [1-3].

a. Commercial and industrial demand

Major water consumption for commercial and industrial use was separately identified and tabulated in Table 1.

Table 1. Categorization of major demand consumption

Range of 30 days water consumption (m^3)	Water consumption (m^3/hr)	Number of locations
90 to 100	3.33	4
101 to 200	6.67	16
201 to 500	16.67	14
501 to 1000	33.33	7
1,001 to 2,000	66.67	9
2,001 to 10,000	333.33	1

b. Domestic demand

Standards prescribed by the NWSDB manual shown in Table 2 were used for domestic demand calculation.

Table 2. Basic data and assumptions for domestic per capita demand

No.	Per Capita	NRW	Peak	Total
	l/day/person	20%	10%	l/day/person
1	120	24	12	156

The geometric population growth rate was used for forecasting the future populations and the estimated current and future demands are tabulated in Table 3.

Table 3. Summary of the calculated demand (m^3/day)

Category	2022	2032	2042
Domestic Demand (m^3/day)	7,485.79	9,125.13	11,123.49
Commercial & Industrial (m^3/day)	1,520.00	2,694.39	4,241.89
Total Demand (m^3 /day)	9,005.79	11,819.52	15,365.38

c. *Demand pattern*

Water consumptions of subscribers significantly vary with time and days and the daily demand pattern which was used in the model is depicted in Figure 3.

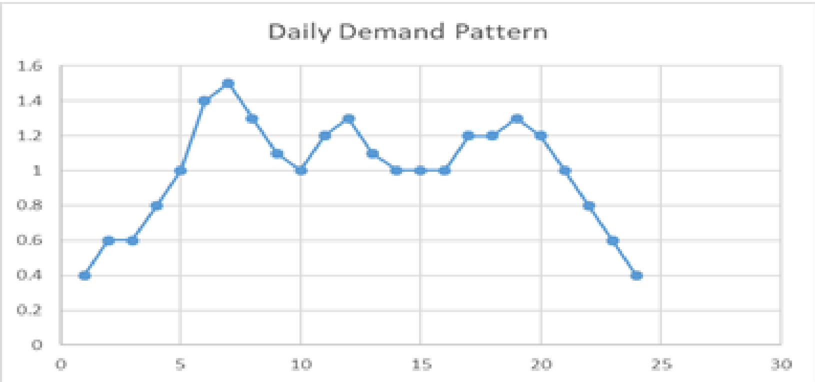


Figure 3. Demand pattern

2.3 Nodal elevation

Elevation of each junction needs to be given to the hydraulic model to analyze them. For this research, the Digital Elevation Model (DEM) developed by the Survey Department of Sri Lanka was used to identify the elevation of pipe junctions. Moreover, GPS (GNSS application) was also used to get the elevation of junctions at certain locations and these elevations were used to verify and correct the elevation obtained from DEM.

2.4 Criteria for study

The criteria adopted for this study are service pressure head, flow velocity, and hydraulic loss gradient.

a. *Pressure head*

The pressure head required in the distribution network depends on several factors, namely the height of the buildings served directly without pumping within the buildings, the maximum instantaneous rate of flow through the service pipe of the building, and friction losses in the pipelines. Moreover, recontamination of treated water is also prevented by the pressure head in the distribution network. Some of the studies suggested that a minimum of 6 m pressure head of water is considered adequate in most instances [4, 5], hence it was considered in this study.

b. Flow velocity

There is no consolidated criteria regarding the maximum velocity in the distribution main [2], however, if the velocity increases to 3 m/s or more the pressure head going to drop off and the water hammer becomes more serious. Moreover, increased velocity can erode the pipe surface and low-velocity causes accumulation of sediments in the drinking water distribution network. Hence, it is recommended that networks to be designed as self-cleansing [6, 7]. Though the threshold design velocity for a self-cleansing drinking water distribution system is set at 0.4 m/s, this value is considered conservative hence, a regular occurring velocity of 0.2 m/s or less may be enough [6, 7]. Therefore, for this study, a maximum value of 1.5 m/s and a minimum value of 0.2 m/s were adopted for flow velocities in the distribution mains and 2.5 m/s for the DI transmission mains.

c. Hydraulic loss criteria

Based on the American Water Works Association (AWWA) recommendations [8], the criteria for head loss gradients tabulated in Table 4 were adopted for this study.

Table 4. AWWA recommendations for Hydraulic loss gradient

Diameter (mm)	J (m/km)
80	50
100	35
125	25
150	15.22
200	6.62
250	2.88
300	1.25
350	0.54

2.5 Network model

The WaterGem model was developed to analyse the distribution network. Initially, the network was drawn using ArcGIS software. In Arc-GIS software, pipelines were drawn as line elements and Junctions (Nodes) were drawn as point elements. A single pipe started with a junction and ended with a junction, and additional junctions were placed where: a) Two or more pipes connecting each other; b) The diameter changing point; and c) Spatial demand required location.

Thereafter, the WaterGem model was developed using the model builder tool. Thiessen Polygon was used to estimate the demand of each node and T-Rex was used to identify the elevation of each node. The network model was analyzed using WaterGem for EPS simulations. Initially, the model was developed and analyzed for the existing network and the corresponding output results were appraised and compared using the study criteria.

Moreover, three separate models were developed by changing future demand having analyzed pipe diameter, network connectivity and the pump capacity for a) Present demand; b) 10 years of demand; and c) 20 years of demand.

3 Results and Discussion

3.1 Calibration of model

Field measurements of water pressure at different points of the distribution pipe network were carried out using portable pressure loggers connected to the consumer meter pipe. Data sets obtained from field measurements of water pressure were used to compare the model predictions. Once all the required data sets were collected, a model was calibrated by changing pipe roughness coefficient, diameter, and minor head loss by trial and error. The detailed water distribution pipe network of the Ampara Water Supply Network and locations where the pressure measurements were taken for calibrating the model are shown in Figure 4, and calibration results (pressure variation with time in the model and the field) corresponding to the aforesaid locations are depicted in Figures 5, 6, and 7.

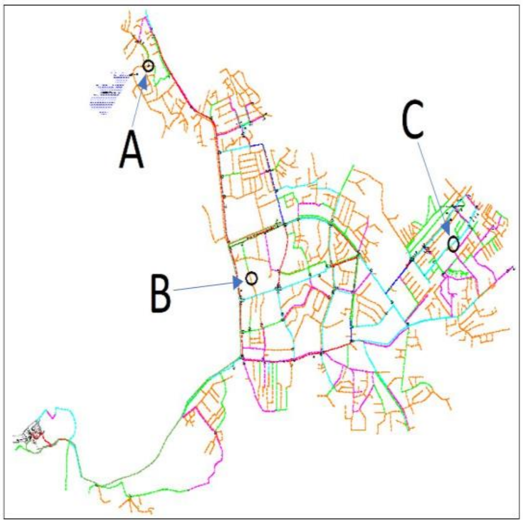


Figure 4. Pressure Logger fixed locations

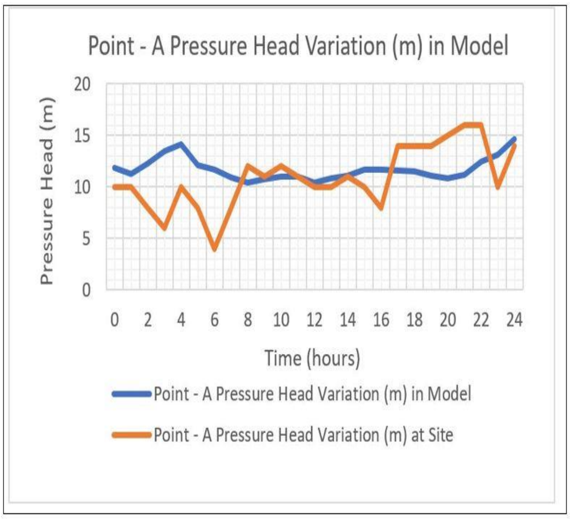


Figure 5. Pressure head at location A

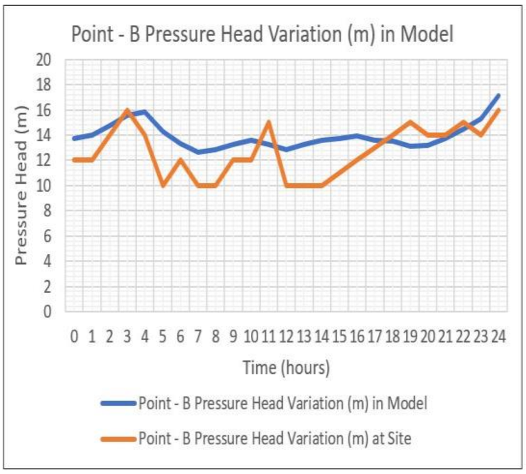


Figure 6. Pressure head at location B

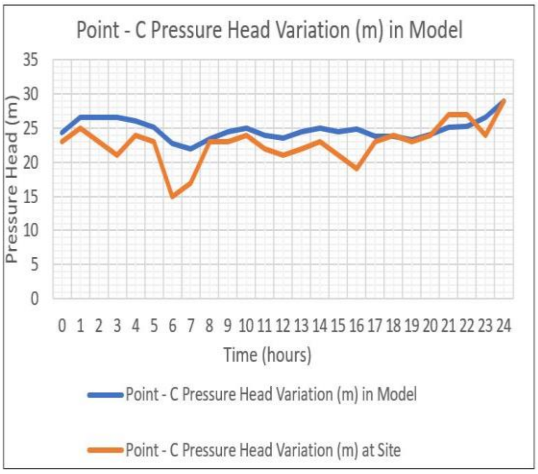
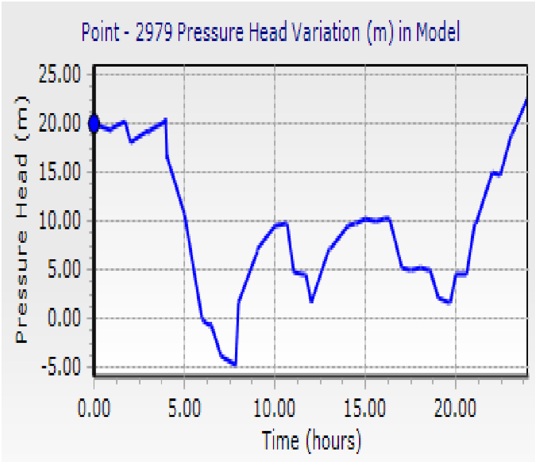


Figure 7. Pressure head at location C

3.2 Present pipe network

The results of the WaterGem hydraulic model of the present network had shown that two of the particular zones getting either low or negative pressure which justified that the "No Water" complaints raised by consumers are true. The pressure variation of some nodes of the present network is depicted in Figures 8, 9, 10, and 11.



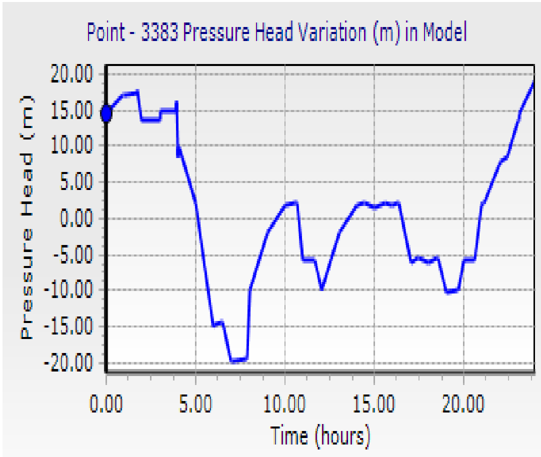
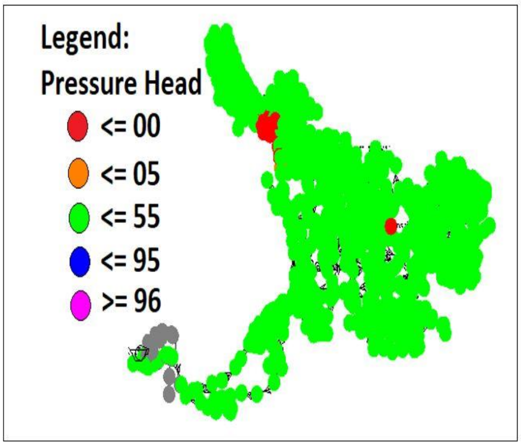


Figure 8. Pressure head at point 2979

Figure 9. Pressure head at point 3383



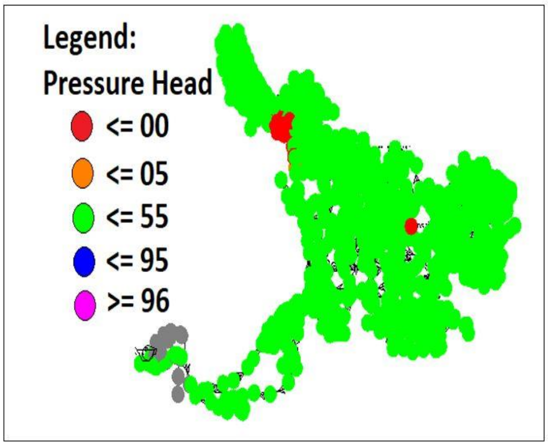
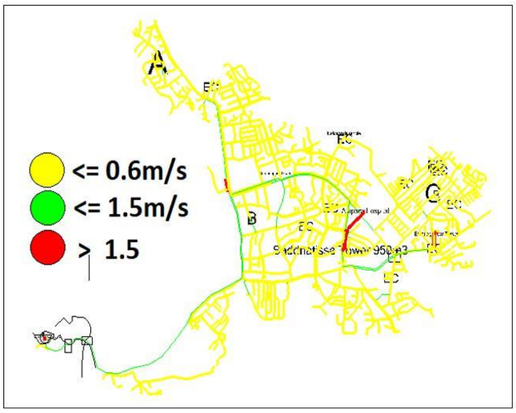


Figure 10. Pressure Head (m) at 08.00 hours

Figure 11. Pressure Head (m) at 12.00 hours

It is noteworthy that the velocity of some pipes was higher than 1.5 m/s which exceeded the threshold velocity of a pipe that is depicted in Figures 12 and 13.



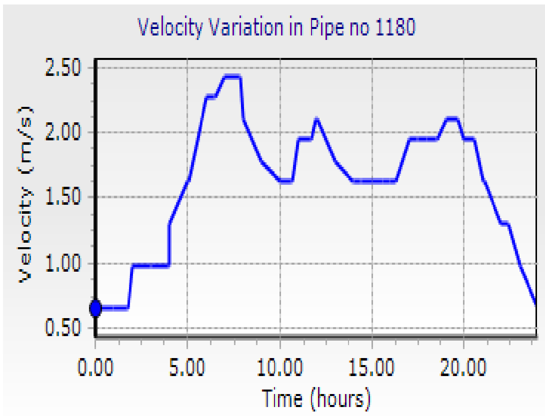


Figure 12. Flow Velocity (m/s) at 08.00 hours

Figure 13. Velocity at pipe no 1180

According to the model results simulated for the present water supply scheme, it can be concluded there are negative and low-pressure zones where required water cannot reach the consumer. The velocity of some pipes is higher than 1.5 m/s which exceeded the threshold velocity, hence those pipes are vulnerable to severe damage.

3.3 Forecasting demand in the years 2032 and 2042 if the present network is used.

The same network without changing the properties was analyzed for the years 2032 and 2042 to forecast demand. The analysed results were shown in Figures 14, 15, 16, and 17. It reflects that the problem identified in the current model increases furthermore in the years 2032 and 2042.

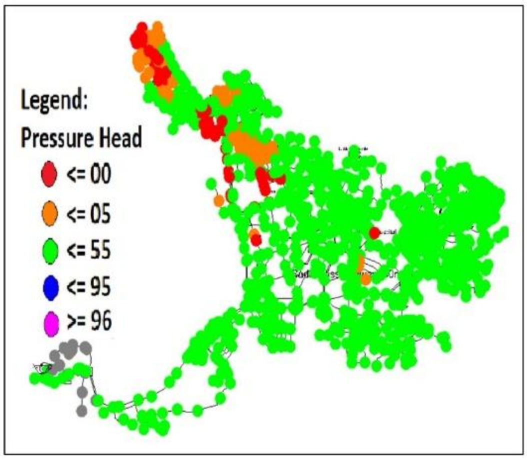


Figure 14. Pressure Head (m) at 19.00 hours (2032)

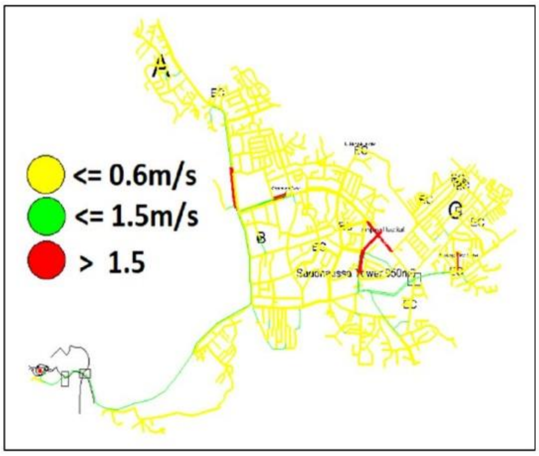


Figure 15. Flow Velocity (m/s) at 07.00 hours (2032)

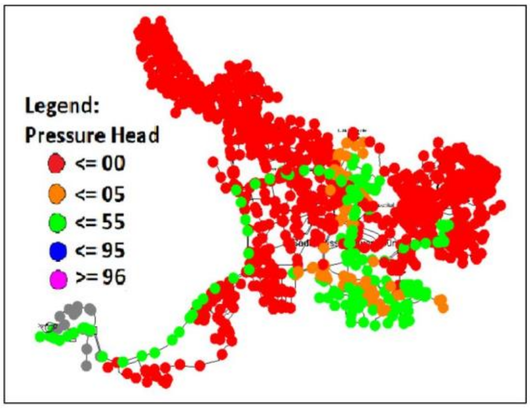


Figure 16. Pressure Head (m) at 19.00 hours (2042)

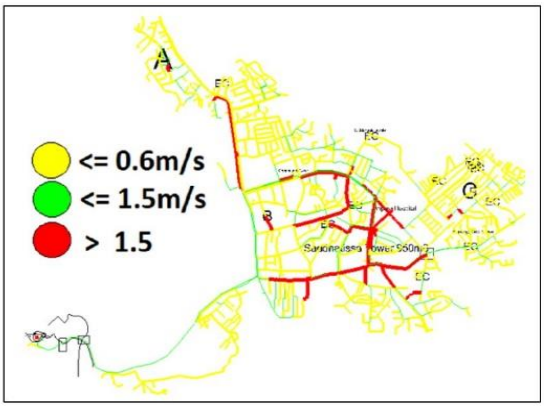


Figure 17. Pressure Head (m) at 19.00 hours (2042)

3.4 Model optimization

It was found from the analyses mentioned in the previous section that negative and low pressure were identified in some pipelines. Hence, the model was required to modify to eliminate the inconsistencies. Therefore, the following changes were made to the current model thereby developing different models for distinct scenarios, and those model results are shown in Figures 18 and 19.

- The carrying capacity of the pipe was increased by changing the pipe diameter where the flow velocity is high.
- Part of the water flow was diverted through the different pipes by changing the connectivity of pipes.
- The overhead tanks were modified as balancing tanks.

- Higher head and flow pumps were introduced.
- Variable Frequency Drive (VFD) was used for the pumping system.

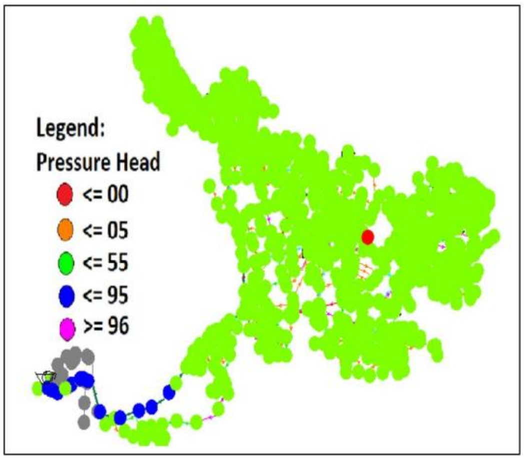


Figure 18. Pressure Head (m) at 07.00 hours

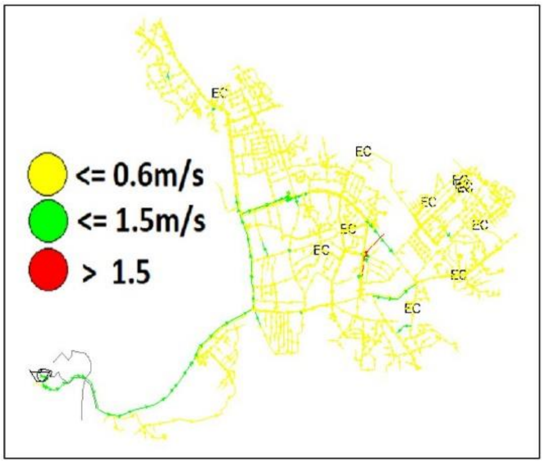


Figure 19. Flow Velocity (m/s) at 07.00 hours

a) Modified Network Model for Present Demand

The model was run for current demand with Interfusing VFD pump, changing overhead tanks as balancing tanks and changing connectivity of pipe without changing the pipe diameters and those results are shown in Figures 20 and 21.

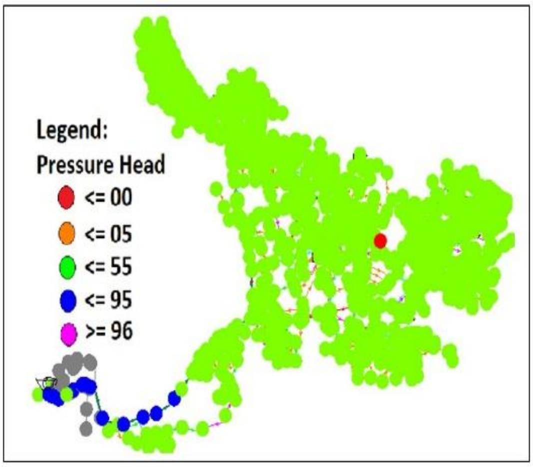


Figure 20. Pressure Head (m) at 07.00 hours

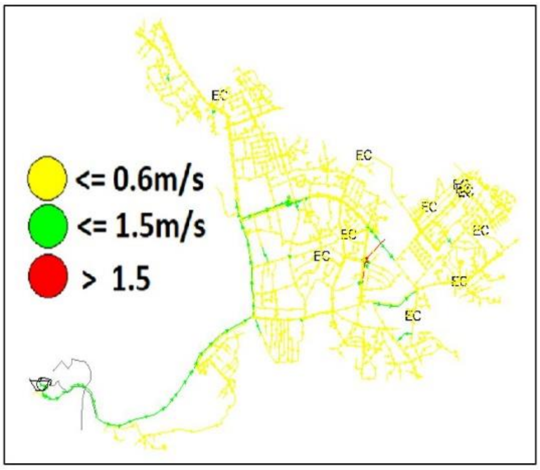


Figure 21. Flow Velocity (m/s) at 07.00 hours

In the present demand, the model satisfies the pressure head and the velocity except in one location which is supplying water to Ampara hospital. The hospital line gets negative pressure from 7.00 a.m. to 10.00 p.m. due to the high flow velocity. The flow velocity, head loss, and the head loss gradient vs time of the hospital line are shown in Figure 22. Therefore, it is required to change the pipe diameter of that line to eliminate negative pressure.

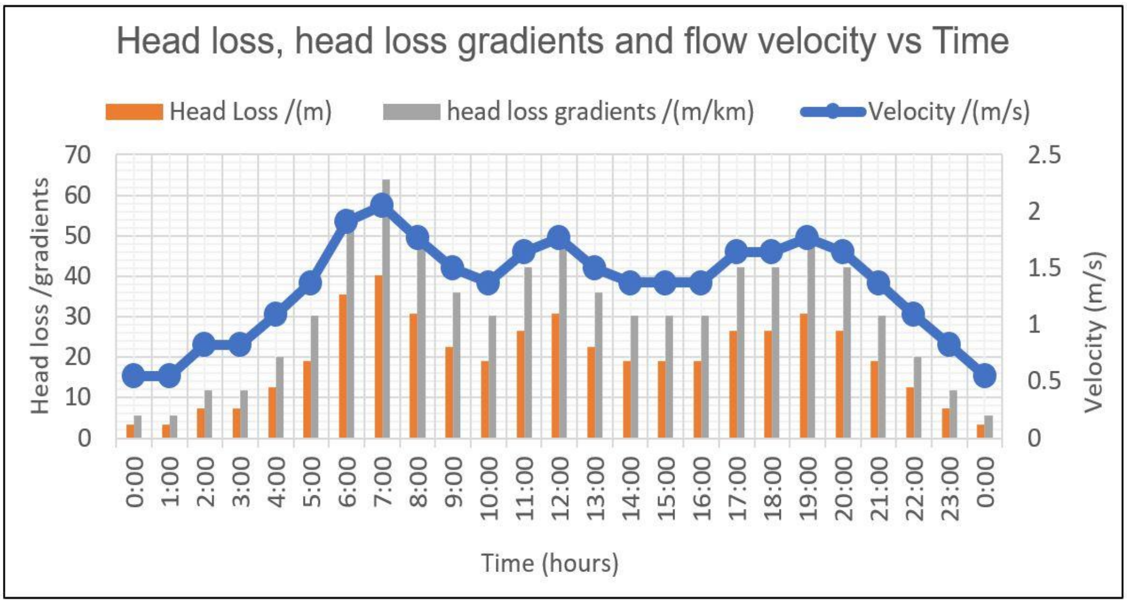


Figure 22. Flow velocity, head loss & head loss gradient vs time of the hospital line

b) Modified network model for future demand

The following changes were made in the model to forecast demand in the year 2032.

- By increasing pump head and flow, changing pipe diameter, and changing connectivity of pipe.
- By introducing VFD to the pump with a higher pump head & flow, changing overhead tanks as balancing tanks, changing pipe diameter, and changing connectivity of pipe.

The following changes were made in the model to forecast demand in the year 2042.

- By increasing pump head & flow, changing pipe diameter and connectivity of pipe.
- By introducing VFD to the pump with higher head & flow, converting overhead tanks as balancing tanks, changing pipe diameter changing connectivity of pipe.

The model results with regard to aforesaid scenarios are depicted in Figures 23 and 24.

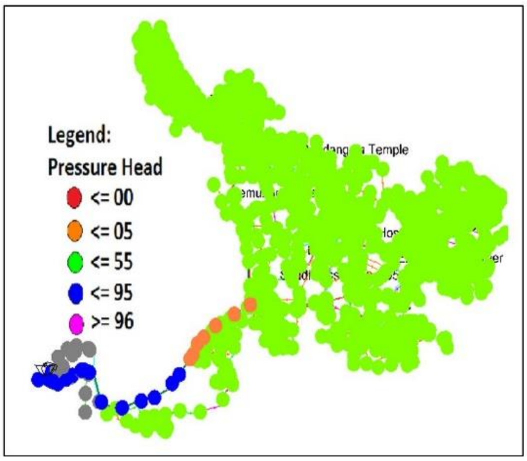


Figure 23. Pressure Head (m) at 07.00 hours for 2042 demand

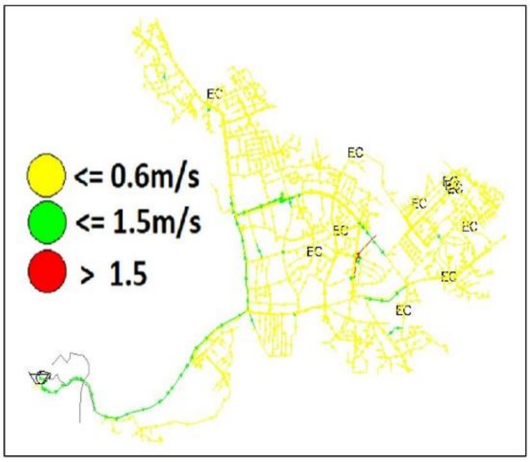


Figure 24. Flow Velocity (m/s) at 07.00 hours for 2042 demand

For the years 2032 and 2042 demands, the network pressure and velocities were satisfied almost in all the locations of the network except some locations. Therefore, to overcome the higher head loss and high velocity, the pipe diameters of particular sections were increased as shown in Figures 25 and 26, and Table 5.

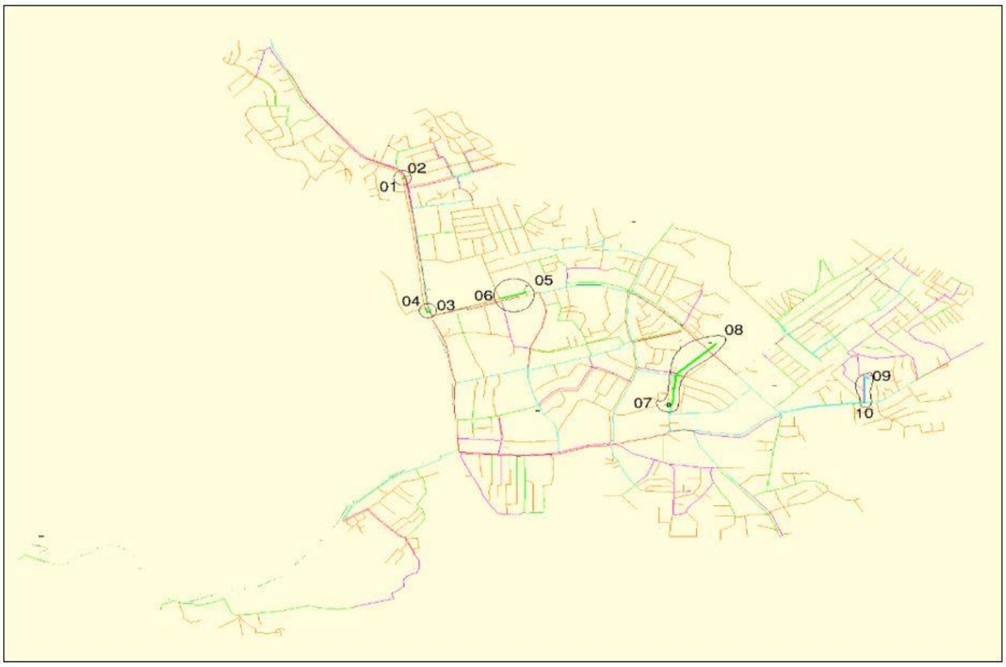


Figure 25. Network with increased pipe diameter for 2032 demand

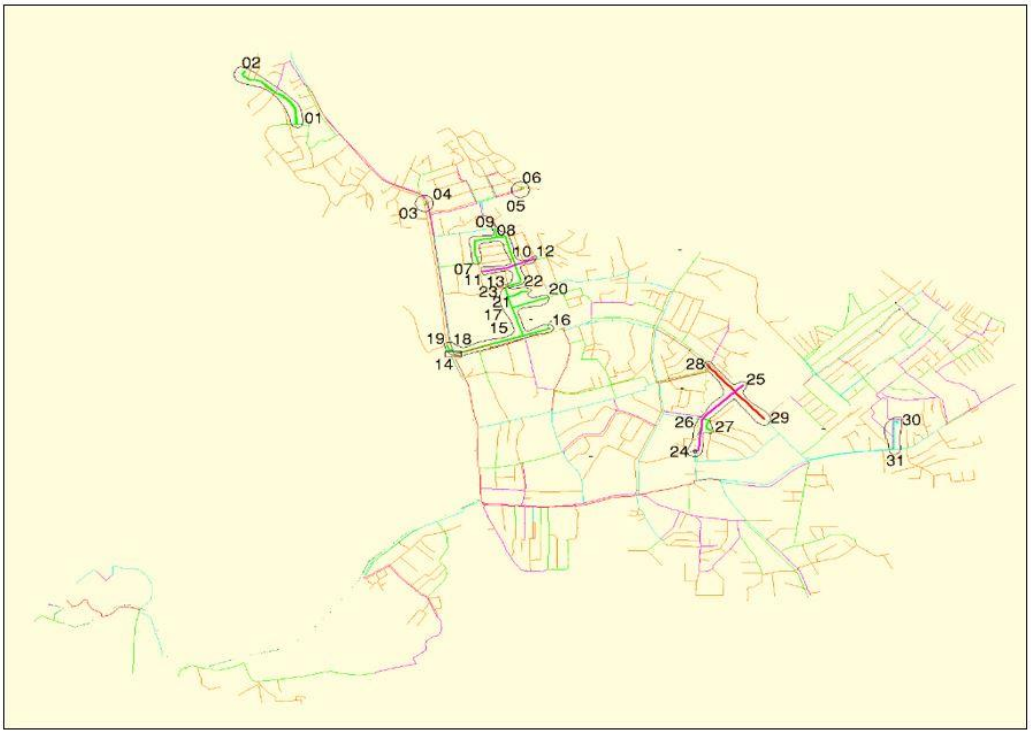


Figure 26. Network with increased pipe diameter for 2042 demand

Table 5. The pipe required to increase the diameter for 2032 and 2042 demand

Year forecast	Node No.	Existing pipe diameter /(mm)	Forecast pipe diameter /(mm)	Length /(m)
2032	01- 02	0	90	20
	03- 04	0	90	65
	05- 06	63	90	185
	07- 08	63	90	630
	09- 10	110	160	245
2042	01- 02	63	90	580
	03- 04	0	90	20
	05- 06	0	90	20
	07- 08	63	90	310
	08- 09	63	90	70
	08- 10	63	90	265
	10- 11	63	110	220
	10- 12	90	110	135
	10- 13	63	90	220
	14- 15	63	90	455
	15- 16	63	90	185
	15- 17	63	90	220
	18- 19	0	90	65
	17- 20	63	90	240
	17- 21	63	90	90
	21- 22	63	90	140
	21- 23	63	90	65
	24- 25	90	110	630
	26- 27	63	90	140
	28- 29	160	225	530
	30- 31	110	160	240

4 Conclusions and Recommendations

4.1 Conclusions

In this study, a hydraulic model application of a water distribution network is presented for the Ampara water supply system where "no water" complaints were raised by consumers. There are several solutions are discussed in this paper. For the current demand, changing the tower to a balancing tank is an immediate and cost-effective solution. Changing Variable Frequency Drive (VFD) with pump for 2032 and 2042 demand is required to have low head and flow rate pump. Therefore, initial purchasing costs as well as the power costs required for operation can be reduced. However, the VFD pumping system requires continuous power supply and operation during the off-peak hours as well.

Moreover, the connectivity of towers needs to be changed as balancing tanks with controls. Furthermore, in the distribution pipe network, some of the pipe sections are to be upgraded with zoning arrangements with necessary changes in the junction connectivity.

4.2 Recommendations

As per the above study, VFD with the pumps and balancing tanks is an optimized solution. To remove the inconsistencies in the network, some of the distribution pipe sections need to be replaced with necessary changes in the connectivity as a result of the year 2042 demand system.

Acknowledgement

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