Hydraulic performance Analysis and Modeling of Water Supply Distribution System of Addis Ababa Science and Technology University, Ethiopia

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Abstract

This study was conducted generally by aiming assessment of the hydraulic performance of water distribution systems of Addis Ababa Science and Technology University (AASTU). In line with the main objective, this study addressed, (1) pinpointing problems of existing water supply versus demand deficit (2) evaluating the hydraulic performance of water distribution system using water GEMS and (3) recommended alternative methods for improving water demand scenarios. The University's water supply distribution network layout was a looped system and the flow of water derived by both gravity and pressurized system. The gravity flow served for the academic and administrative staffs whereas the pressurized system of the network fed the students dormitories, cafeteria's etc. The study revealed the existence of unmet minimum pressure requirement around the student dormitories which accounts 25.64% below the country's building code standard during the peak hour consumption. The result of the water demand projection showed an increment of 2.5 liter per capita demand (LPCD) in every five years. Hence, first, the university's water demand was projected and then hydraulic parameters such as; pressure, head loss and velocity were modeled for both the existing and the improved water supply distribution. The finding of the study was recommended to the university's water supply project and institutional development offices for its future modification and rehabilitation works.

Keywords: Water Demand, Water Supply, Performance, Hydraulic Modeling, Water GEMSV8i

1. Introduction

Currently, guaranteeing access to safe drinking water is one of the most problematic in the global world (Alicia et al., 2020).The access to water is crucial for life, prosperity, and all human activities and Water resources must be used effectively to meet the demand of the ever-growing population, considering the limited and decreasing water availability (Taha et al., 2020). A water distribution system is a complicated combination of hydraulic control parameters connected together to transmit of water from sources to consumers(Abhijeet, 2018) and Network condition is defined as collectively representing the physical condition state of all water pipes in the network (Kambiz et al., 2019). Pipes with in poor condition in water distribution systems cause significant operational problems (Mahmut et al.,2019) and together with difficult site terrains and complicated site layouts which pushes up connection costs, the cost of water relative to low family incomes, illegal status of settlements, the transient nature of residents, lack of political will, poor community participation, lack of competitive policies and strategies, and the susceptibility to corruption and politicization of service

deliver (F.D.,2018). Therefore, it is important to evaluate the technical performance of these pipes (Mahmut et al., 2019).
Pressure driven approach and demand driven approach are main points in such network simulation scenarios. While allocating demand at a junction in software the pressure at that particular junction should be sufficient. Pressure driven approach gives an advantage when the system is having pressure deficient condition. Practical application of this approach is possible above mentioned case. (Abhijeet, 2018). There are some mistakes in the main pipe network; the elevations of the nodes are not assigned, so there are some errors and assigned elevations for all nodes on the pipeline network based on mean sea level (MSL). After adjusting the elevation of each node, it was found that the new pipeline network has increased the correlation between means for the existing model (Rangsan et al., 2018).

Hence, adequate water distribution is one of the international goals for sustainable development (Renwick, 2013).However during operations of water supply systems, cases of pressure drops main challenge is the lack of a simple tool to accurately predict zones of low pressures and areas where quality is compromised. (Christopher et al., 2015)
The availability of drinking water has been one of the major global concerns in recent decades (Rosinele et al.,2019) and particularly, developing countries face greater challenges of adequate water distribution because of their larger population growth rate, poor infrastructure, lower income levels, and less developed policy and institutional capacity (Kochhar et al., 2015). Rising water demand as a result of population growth and urbanization has an effect on the availability and reliability of existing water distribution system. Therefore, water demands need to be assessed on the basis of considering the year and date supplying water through the distribution system.
Several hydraulic modeling approaches have been proposed previously to simulate pressure - deficient operating conditions in water distribution networks more realistically (Alemtsehay and Tiku, 2016).

Hydraulic models of water distribution networks (WDNs) are efficient decision support tools for development of various management scenarios to improve efficiency and reliability of existing networks and to design new ones. In hydraulic models, well-known hydraulic equations are solved to calculate main hydraulic parameters; such as flow rate, velocity and water pressure, at many points for the described WDN and the obtained results are displayed in tabular and graphical forms to be evaluated by the users. The success of hydraulic model predictions depends on accurate determination/estimation of input parameters and model calibration and verification studies. (Shaoyuan et al., 2019 and Ethem, 2016).
Currently, in the operation of urban water distribution networks (WDNs), the supply pressure to users should be kept low while meeting the lower bound to satisfy users' water demand, reduce leakages and power consumption(Shaoyuan et al., 2020) WDNs are equipped and controlled with Supervisory Control and Data Acquisition systems to improve network efficiencies and its systems could be integrated with well calibrated and verified hydraulic models to provide useful input data sets for model set-up and comparison with model predictions. In routine monitoring and control studies of WDNs, only limited number of monitoring and control points are selected on the WDN to collect hydraulic data. However, an

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accurate calibration and verification study of hydraulic models requires simultaneous and precise estimation of many hydraulic parameters such as flow rate, water pressure, etc. for the whole WDN (Ethem K.et al., 2016).

2. Materials and Methods

2.1 Location of study area

The study area, Addis Ababa science and Technology University (AASTU) is geographically situated at 8º 53'30''N and 8 52'30''N latitude and 38º 40'30''E and 38º 49'0'' E longitude with elevation of 2148 meter above sea level .The relative location of AASTU campus is in the southern part of Addis Ababa which is the capital city of Ethiopia through the road taken to Akaki Kaliti sub city with the specific name of Klinto and specifically found in woreda (district 9 beside Klinto prison as shown from Figure 1). According to the registrar statistics the last census population data of campus was 8015 for the year 2008 G.C

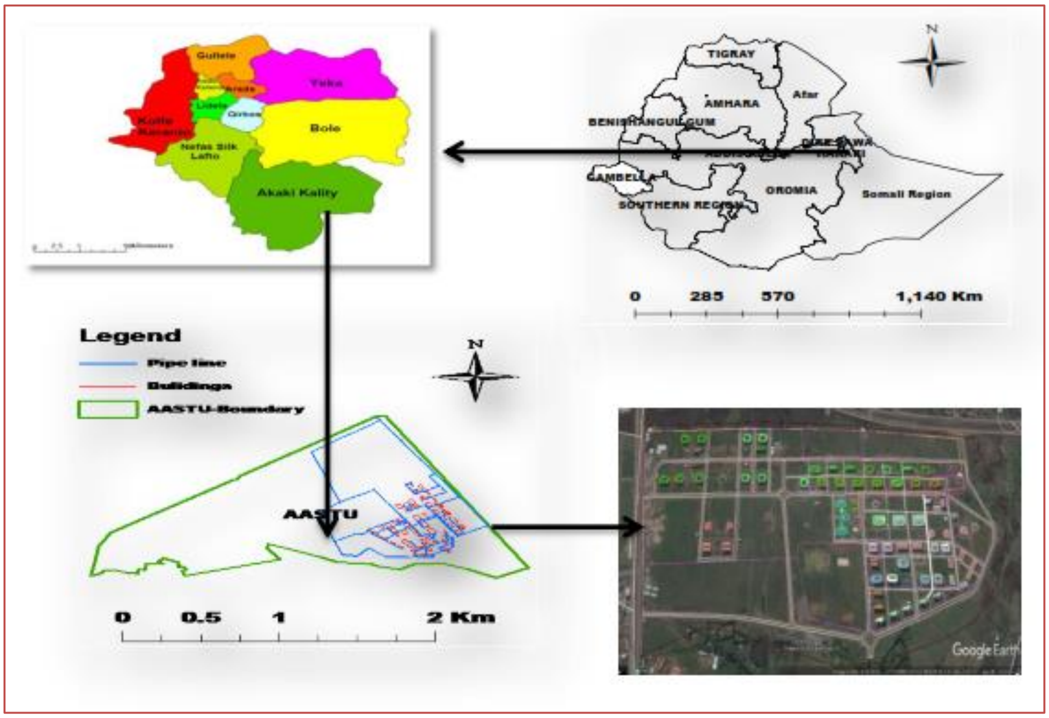

Figure 1: Addis Ababa science and Technology University

2.2 Topography and slope

The area is bounded by two streams in the north and south. The university compound is flat to undulating with a general slope of about 3% from west to east and an elevation of the compound varies from 2117 to 2192.

2.3 Climate

Rainfall is characterized by a bimodal rainy season having main rain and small rain season. The main rainy season has three months of duration (July, August September) on the other hand the small rainy season extends from March-April. The annual rainfall of the town is highly variable and ranges from as little as 850 mm to as much as 1200 mm.

The mean maximum and minimum monthly temperature is 27^0 pan evaporation is about twice the average annual rainfall.

2.4 Population

The base or current population of the university 8015.The following assumptions is made based on Addis Ababa Science and Technology University population dynamics.

- Students number will increase by 2300 every five year
- Supporting Staff number will increase by 200 every five year
- Gardening Demand - 1 mm/day for the 47.7 ha of the garden area
- Construction Demand - 10% will decrease by 2% every 5year

(Source: Project office, 2019)

2.5 Existing Water Supply System

The University was obtained its water from Addis Ababa and Sewerage Authority (AAWSA) 695 m^3/day supply in the late 2012 year (Institutional and development project office 2019).The Addis Ababa Water and Sewerage Authority (AAWSA) is a public institution in the city, which is responsible for the supply of potable water partial for AASTU campus and AASTU purchased its water from the Akaki Water Bureau (AWB) through the district of Klinto water system. In the system, water is distributed to consumers from the three means of water supply distribution which means such as gravity distribution, distribution by means of pumps with storage and use of pump without storage, from these all types of water distribution system AASTU consider both the gravity type of distribution and pump with storage distribution as shown from figure 2.

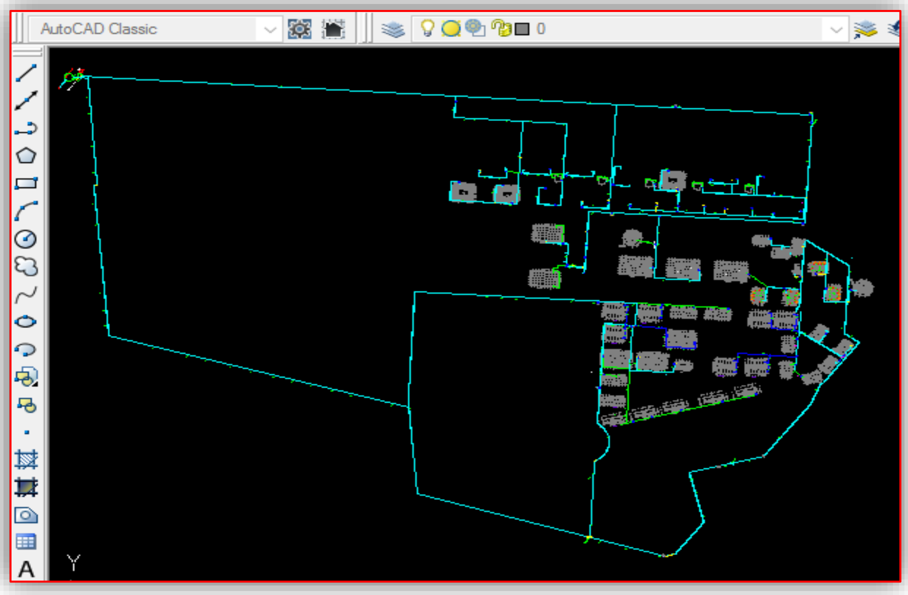

Figure 2: Existing water supply distribution systems

2.5.1. Storage Reservoirs

Water system has two reservoirs with a total combined storage capacity of 1050 m^3 and those two existing storage reservoirs are ground service reservoir and elevated tank (reservoir) which contain the volume of 1000 m^3 and 50 m^3respectively as shown from figure 3.

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Figure 3: service and elevated tank

2.5.2. Pump Stations

The campus water supply distribution system includes two booster pump stations, the existing Pump Station as shown from Figure 8a and the new under construction borehole Pump Station. The existing pump station is located in AASTU campus adjacent to the ground reservoir and houses the three pumps with an approximate total capacity of 164 meter cubic per hour (m3/hr.) as show from figure 4.

Figure 4: Pump house and pumps

2.5.3. Types of water supply distribution systems

From the four types of water supply distribution Systems University's water supply distribution system is a loop type system. The maintenance operation did not affect the interruption on the whole area as in the branching system and this type of layout is highly desirable because, for any given area on the grid, water can be supplied from more than one direction.

2.6. Materials

2.6.1 Source of data

The source of data was involved both primary and secondary data. For the study, the primary data were obtained from pressure reading and by made of discussion with water utility staff members to obtain additional relevant information on the subject matter. While, secondary data were collected from different literature reviews, design report, the town water supply service office existing documents and annual reported papers.

3.6.2 Equipment

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GPS instrument was used to collect the required elevation data during pressure reading. Pressure readings were done using pressure gauge which is commonly taken in the selected points of distribution system.

2.6.3 Software: Water GEMS

Model is something that represents things in the real world and computer model uses mathematical equations to explain and predict physical events. Modeling of water distribution systems can allow determining system pressure and flowing rate under a variety of different conditions without having to go out and physically monitor the system (Dawe, 2000).

Water GEMS is a state-of-the-art software tool and, primarily uses in the modeling and analysis of hydraulic and water quality modeling application of water distribution systems. But, the methodology is applicable to any fluid system with different characteristics, such as: steady or gradually-varying turbulent flow (Water CAD: *User Manual*) as shown from figure 5.

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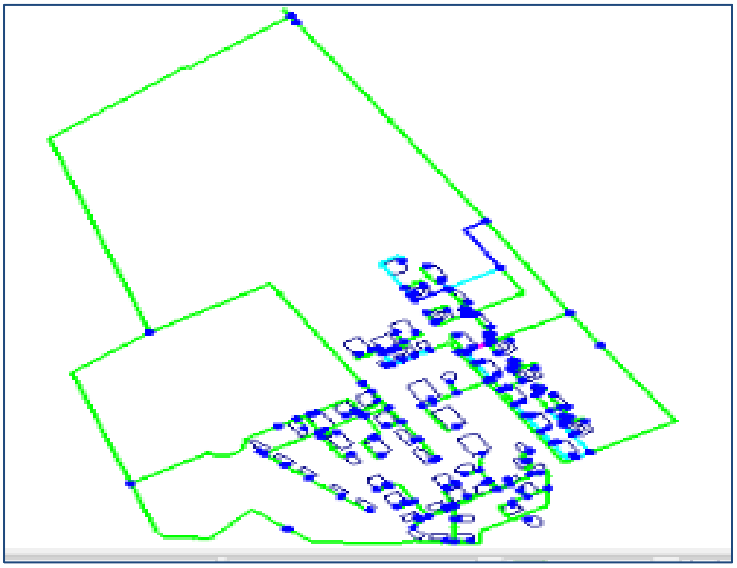

Figure 5: Water GEMS layout

2.7 Method

2.7.1 Data source and collection

The most important step in any research study is data collection. Primary and secondary data are used and collected from different sources. For primary data house hold survey and direct observation were employed. On the other hand, the major source of secondary data include design document in AASTU, inventories from Addis Ababa Science and Technology University and related literature. Information on organizational structure, manpower situation, design and water system detail were collected from design document and related literature.

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3. Results and Discussion

3.1. Existing Water Supply Assessment

Demand projection was the common constraint during designed by consulting industry. According to country's building code of standard the per capita demand for boarding school in liter per capita per day (LPCD) was 60 LPCD which contradict previous designed document of 110 LPCD. As a result of this designed constraint estimation 754 m^3 per day water demand was over estimated as shown from figure5. Consequently, an estimation of university's the water demand conjunction with poor management of the existing water supply infrastructure had a great impact for the low coverage during average and peak hour demands particularly around students dormitories. Actual average water demand estimation showed that, the total amount of water demand required by university would 1167 m^3/day for continuous systems or supplying water for 24 hours. From this information, 672(1167-695) m^3/day amount of water is deficit available in university as shown from table1.

Table1: Demand projection between cities and boarding school criteria

Description	Year	2015	2020	2025	2030	2035
Population Projection	No.	6400	8900	11400	13900	16400
Cities criteria	LPCD	110	113	116	118	121
Existing Demand	m^3/day	704	1006	1322	1640	1984
Boarding school criteria	LPCD	60	63	69	72	75
Projected demand	m^3/day	384	561	787	1001	1230
AAWSA	m^3/day	695	6945	695	695	695

3.2. Observed and simulated pressure

The credibility of a model is merely evident if a model results precisely reflects observed field values. Thus, to have a confidence on model result it needs to calibrate a model. was presented as follows. An effort to perform hydraulic network and water quality model calibration and validation for this case study as shown from figure 6.

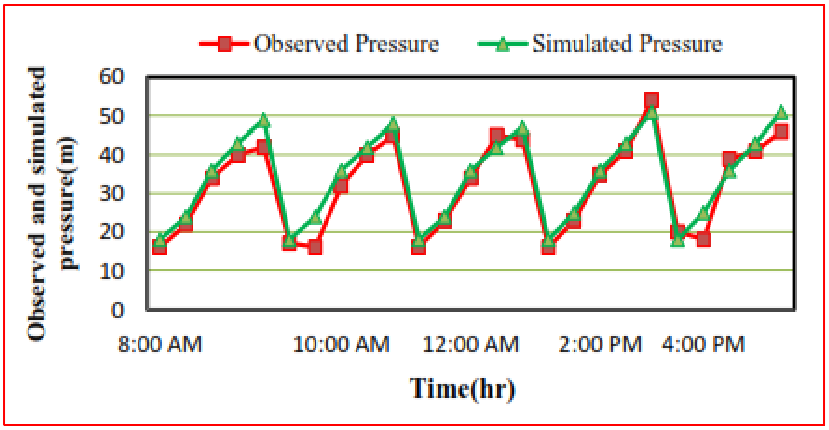

Figure 6: Observed and simulated pressure correlation

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Pressures were measured in the field in order to compare with the results of the distribution model as shown from Figure5. The diagonal line on the plot represents the line of perfect correlation in Figure 6 below here. Ideally all the points should align themselves on this line; meaning that all observed pressures would be equal to the computed pressures, giving a correlation coefficient of 1 that is the best correlation between observed and simulated. The linear correlation coefficient (R) of observed versus computed pressures is calculated by Equation 6 value is at 0.94. The coefficient of determination (R^2) value was 0.94, it indicates that observed and simulated relation is strongly as values tend to 1 as shown from figure 7.

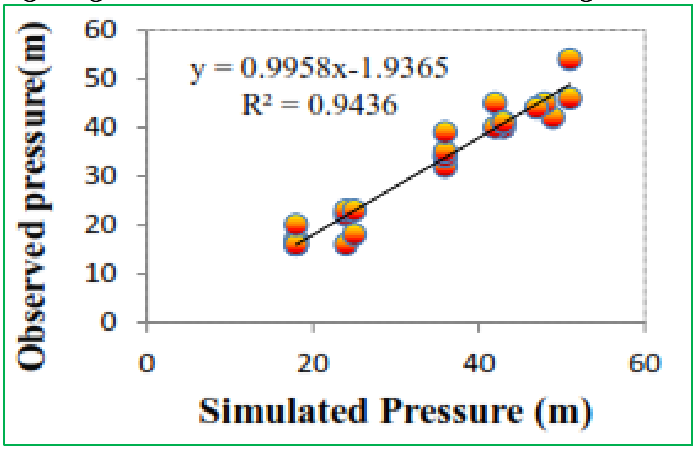

Figure 7: Correlation between observed and simulated of parameters

3.3. Identified Problem and Improvements

3.3.1. Pressure

Models are the footprint in finding the cause of the interruptions or problems and then, Addis Ababa science and Technology University water supply distribution has the following major problems as shown from figure 8.

- Low pressure around student dormitories.
- High head loss through the pipe length
- The pump is not used effectively

The system was modeled with two demand patterns. The first pattern was assigned to all the nodes for the student with 2 hour peaks between 7 and 9am and 5 and 7pm. A second pattern was defined for staff. There are three identical pumps at the pump station adjacent to ground reservoir each delivering $82m^3$/hrs to 34m. The minimum level in the tank was set at 21.5m to ensure a minimum pressure to drive water within the distribution system.

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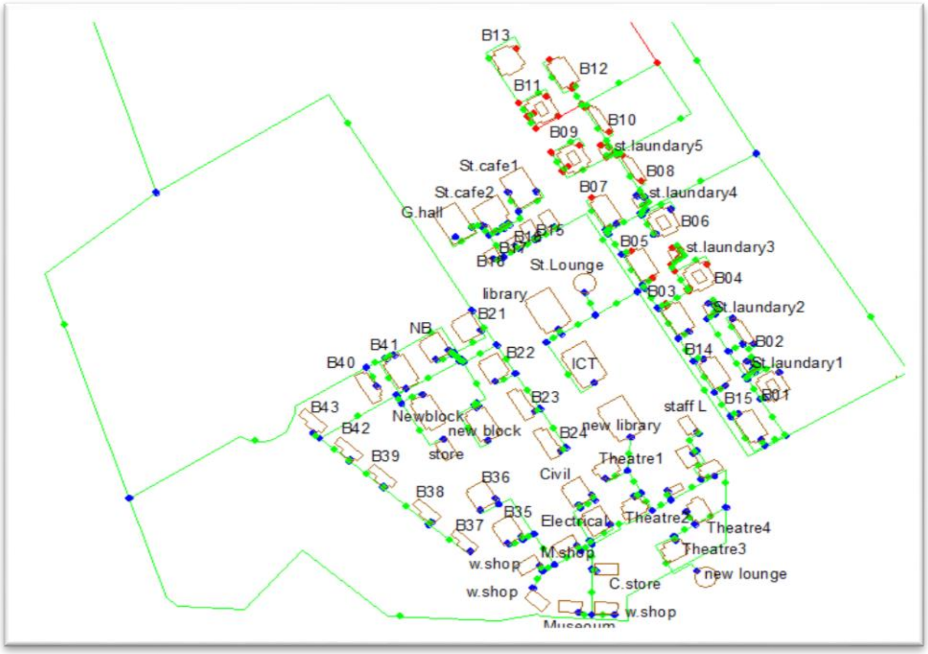

Figure 8: Identified negative nodal pressure with corresponding blocks

3.3.2. Velocity Distribution in Actual Pipe

Velocity of water flow in a pipe is also one of the important parameters in hydraulic modeling performance evaluation of the efficiency of water supply distribution and transmission line and the velocity range under diurnal flow pattern for the study area was in the range of 0-2.63 m/s. The previous friction factor in these pipes was Hazen William and adjusted to Darcy Weisbach since it is global acceptable. The maximum head loss in the pipe was 102.75 m/km and when this pipe was optimized, and then the head loss was observed to be 6.87m as shown from Figure 9. This is a considerable increase in the amount of velocity, especially since the velocities are generally medium in the study area.

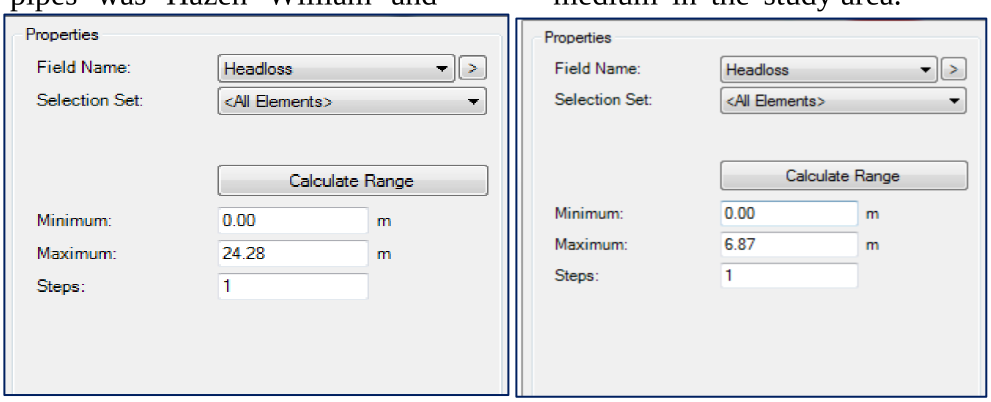

Figure9:Headloss in existing vs modified the water distribution systems

For this study velocity is considered as criteria during resizing the pipe diameter. Velocity has also a great impact on water quality as turbidity and the like. Carried out Modeling is helpful in pinpointing the cause of hydraulic efficiency problems. In general

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the study area of water distribution system has the follow ing major problems with respect to hydraulic network modeling as mentioned below on shown figure 10.

- Undersized service pipe diameter
- High velocity
- Low velocity

Undersized pipes can usually be found by looking for pipes with high velocities. Increasing the diameter of the pipe in the model should result in a corresponding decrease in velocity and increase in pressure

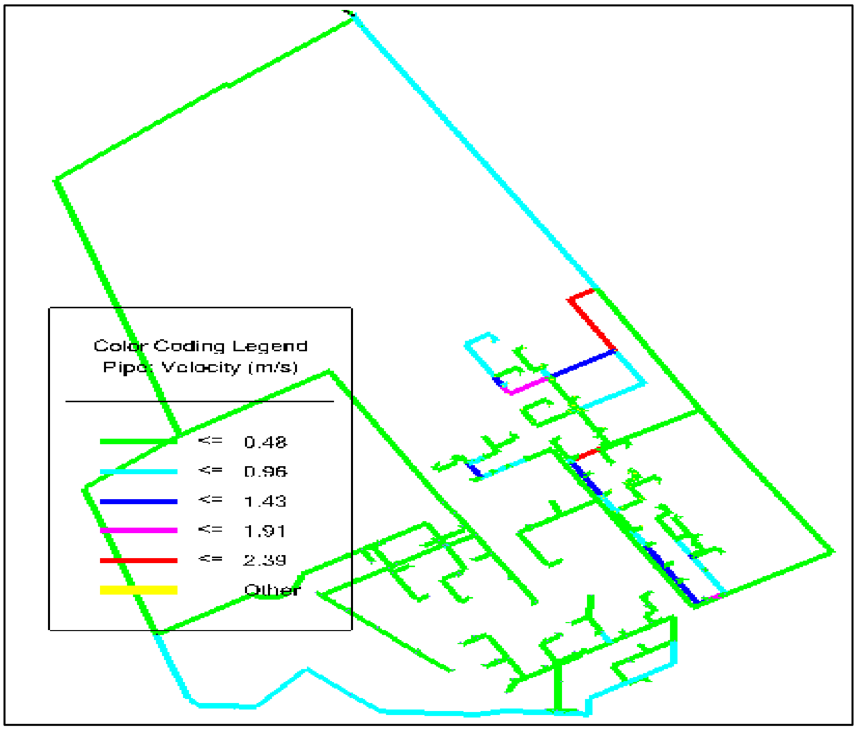

Figure 10: velocity variation in the pipe

3.4. System Model Improvements

In designing or improving a system there are sets of design criterion to be considered, for pressure and velocity. The design criteria used in the design of water supply distribution system components, nodal pressure during the period of peak demand, and optimum velocities of the transfer and distribution mains were used(ShaherH.,2003).Hence, the system was completely modified as shown from figure 11 below.

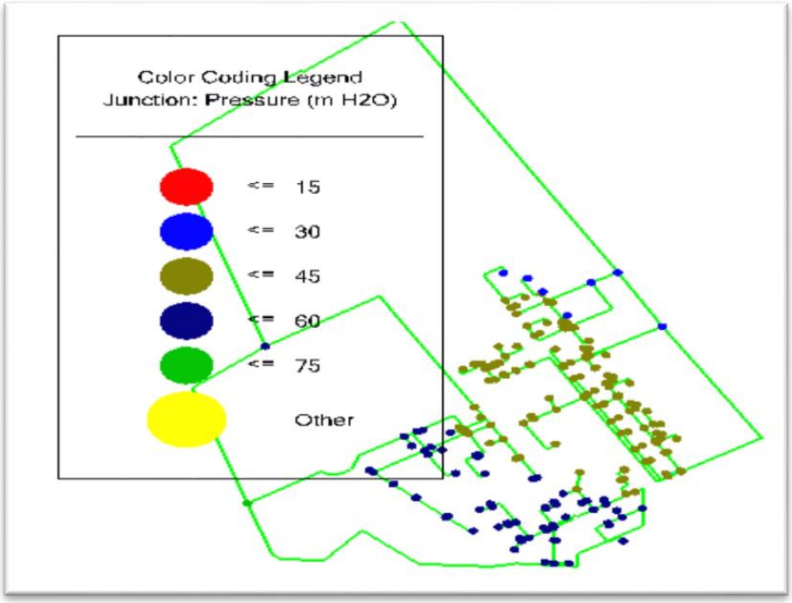

Figure 11: Pressures for improved water supply distribution

4. Conclusion and recommendation

4.1. Conclusion

Relevant data required for the analysis were collected and results of all the analysis were supported by charts, screen prints and pictures. The analysis revealed a gap between the current water supply and the water demand in the university. The analysis of the existing water distribution shows a rather inefficient network which is the reason for lack of flow supply to some parts of the university. The pressures at the nodes are generally low and the quanta of water flowing in some pipes are inadequate and a major defect in the network is the fact that Tank, which is the biggest and at highest elevation, is not being put to optimum use currently.

4.2. Recommendation

In order to conclude and enhance quality of water supply distribution system the following recommendations were made:

- If convenient and affordable, the university should carry out a test to find out the specific capacity of its undergoing well construction for sustainable and also perform a drawdown test to have a better knowledge of its supply system for the future.
- It is most recommended that the blocks located around students have additional pressure tanks installed near their blocks and use booster pumps to solve the problems of poor pressures at their locations.
- The university must make plan for further study on conditions or factors affecting, its water distribution system, especially on poor design, the quality water for future to address ground water safe from wastewater (condominium).
- Eventually, a serious issue has to be considered for water project infrastructures as whole in a

country.

Acknowledgments

The author would like to acknowledge Addis Ababa science and Technology University for helping this research work and also, we like to acknowledge the editors of the journals.

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