Hydraulic Performance Modeling and Improvements of Water Supply Distribution Systems

Zerihun Abiyu[1] Dr.Ing. Geremew Sahilu[2]

Abstract

Water Supply Distribution Systems Utilities are designed to Continuously supply safe, reliable and affordable, potable water to end users. As time elapses, meeting these commitments embraces multiple challenges in urban areas. The objectives of this work are to evaluate the hydraulic performance of water supply distribution system by assessing the situation of existing water supply distribution system. This is mainly done by estimating the water loss in the system in order to improve the efficacies of the water distribution networks and to determine remedial measures.

Water GEMS software is used to model water distribution system. It is used to identify the high pressure and low pressure at junctions and velocity magnitude and head loss of flow in pipes which are used as basis to evaluate the hydraulic performance.

Results showed violation of maximum and minimum pressure and low velocity requirements. High pressures in the system occurred both during low demand and peak demand and remedial measures are found by providing pressure reducing valves. It is also proposed to install air release valves at high elevation and sluice valves at low elevations. Modifications in operation and design can improve the performance of the current water supply distribution system of the case study area.

Key Words: Hydraulic Performance, Maximum pressure, Minimum pressure, Water Distribution System, Water GEMS Modeling, Water Loss, Ginchi, Oromia, Ethiopia.

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1. Introduction

In earlier times water distribution systems were not complex. The systems were made of single lines or very few lines. As town grew to larger and denser populations greater need for complex water infrastructures evolved.

This research focused on the hydraulic performance of water distribution network system at Ginch Town, West Ethiopia. The continuous and repeated deficiency in the performance of the Ginchi Town water supply distribution networks is one of the most critical issues in the water supply sector that requires immediate action.

The town water supply distribution systems is designed to adequately satisfy the water requirements continuously for a combination of domestic, commercial, industrial, and firefighting purposes. The system should be capable of meeting the demands placed on it at all times and at satisfactory hydraulic performance. It should enable reliable operation during irregular situations and perform adequately under varying demand loads **(TAHAL, 2015).**

The majority of the WDS of the town were built decades ago; many are approaching or have exceeded their design lives and their performance has gradually declined. Population is growing rapidly with expansion of the town. Due to this hydraulic performance of water distribution system of the town is facing serious problems. The old system requires extensive up grading and analyzing operation of systems is crucial. Analysis of the Ginchi town water distribution pipe network is essential to understand the hydraulic performance of systems.

Although much attention has been paid to the hydraulic performance assessment of water distribution systems, some important areas have not yet been investigated fully:

1.Various criteria in social and environmental costs resulting from the performance of water distribution systems.

2.The growing awareness of the quality of service requested by all customers and 3.Assessment of new approaches for improving performance of current operating systems to include more comprehensive public and economic issues.

However, measuring the hydraulic performance of a water distribution system as a multi-purpose system is a complex task since it can be perceived from different viewpoints and related to a variety of parameters and properties of the system which are not usually quantifiable.

This study is to evaluate the hydraulic performance of the Ginchi Town water supply distribution system . By investigating and under varying conditions in order to suggest remedial measure for sustainable use. This research seeks to establish a broad perspective for the evaluation of the design and operation of water distribution systems. The main goals are to bring to the attention of the designers, and decision makers to issues that have been often neglected in practice, and to test and verify new ideas for system design and operation.

1.1 Objective of the Study

General Objective

The main objective of the study is to analyses the hydraulic performance of Ginchi town water supply distribution network and identify existing problems via of proposing more efficient distribution system.

Specific Objective

The specific objective of the study:-

- To evaluate the situation of existing water distribution system and increase the efficacies of the system .
- To identify major factors that are contributing to deterioration of the system hydraulic performance.
- To examine the levels of the real and apparent water losses in the system.
- To suggest the optimal solutions which support the sustainability of the town water distribution system.

2. Research Methodology

2.1 Description of the Study Area

Ginchi Town is found in Ethiopia between 404362.74E to 408005.87E and 998126.30 N to 997663.10 N UTM 78km west of Addis Ababa, Fig. 2.1. It has an area of 6.5 km^2 and its altitude ranges from 2231 to 2380 m above sea level. Boundary of the town and lay out of water distribution network is as shown in fig. 2.2 . The present population is estimated to be 53,600 with an annual growth rate of 4.1 %(Oromia Regional Finance and Economic Development Bureau).

The town possesses a complex mix of medium climate zones, with an average temperature 18°c, depending on elevation and prevailing wind patterns. According to National Meteorological Agency of Ethiopia, mean minimum and maximum temperature of the day varies from 15°c to 27°c. The main rainy season is from June to Mid -September and the hottest and driest months are April and May. The shortest rainfall period is March to mid-April, and it is characterized by relatively cool nights and warm days.

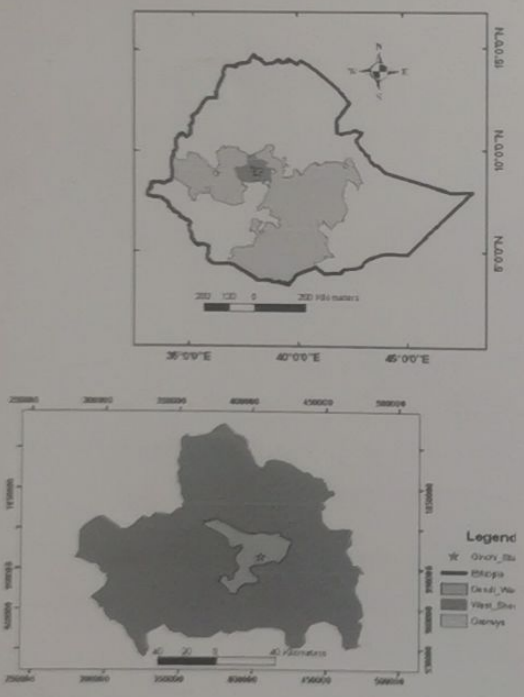


Figure 2-1 : Location of study area(Ginchi town)

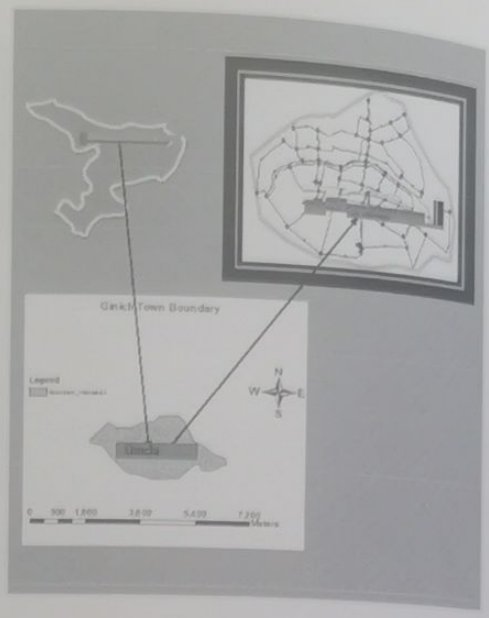


Figure 2-2: Ginchi town boundary and water distribution network

2.2 Description of the study process

The approaches adopted to study each of the system components are shown in fig 2.3.

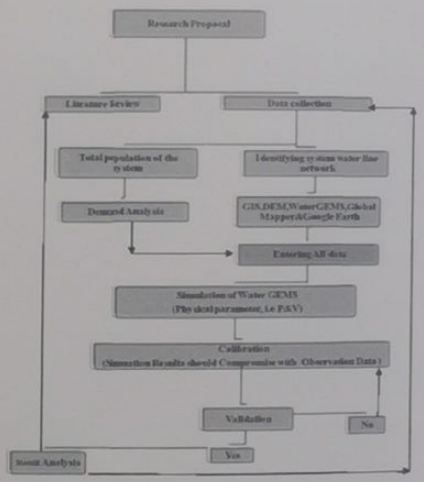


Figure 2-3: Study flow chart

2.3 Water Distribution Mathematical Model

2.3.1 Purpose and suitability

Hydraulic models are often used to validate the design of new or rehabilitated pipelines. They are also used to verify the system capacity or to analyses the effect of modified

infrastructure within the entire water distribution system or its sub system.

Models have become an essential tool for the management of water distribution systems

around the world. There are numerous purposes for using a computer model to simulate the flow conditions within a system. A model can be employed to:

- Ensure adequate quantity and quality service of the potable water resource to the community.
- Evaluate planning and design alternatives
- Assess system performance
- Verify operating strategies for better management of the water infrastructure system.

Perform vulnerability studies to assess risks that may be presented and affect the water supply.

Water distribution network mathematical models have become increasingly accepted within the water industry for simulating the behavior of water distribution systems. They are used to support the decision-making processes in various utility management applications including planning, design, operation and improvements of water distribution systems.

Water CAD, Water GEMs, Epanet, WaterNetGen and GIS are most popular and powerful models that simulates the behavior of water distribution systems in the real world are available on website.

For the case of this research **Water GEMs** modeling software is preferred due to its multi-species modeling capabilities and its integration with GIS software(Alaeddinne Eljamassi, Rola Ahmead Abeaid, 2013).

2.3.2 Model Calibration and Verification

Model calibration and verification based on the observed data is required to establish the necessary level of accuracy of the hydraulic model. Calibration and validation is also required to develop trust in the ability of the model to represent what is currently happening in the system and what can happen under future scenarios. Hydraulic model is typically calibrated and verified based on the flow and pressure measurements throughout the system.

Calibration of water distribution model is a complicated task, see Fig.2-4. There are many uncertain parameters that need to be adjusted to reduce the discrepancy between predicted and observed values of junction HGL and pipe discharges. Pipe roughness coefficients are often considered for calibration. However, there are many other parameters that are uncertain and affect junction HGL and pipe flow rate. To minimize errors in model parameters and eliminate the compensation error of calibration parameters. one should consider calibrating all the model parameters, such as junction demand,

operation status of pipes and valves, and pipe roughness coefficients.

A typical network representation of water network may include hundreds of link and nodes. Ideally , during the water distribution model calibration process, the roughness coefficient is adjusted for each link and demand is adjusted for eachnode.However,only a small percentage of representative sample measurements can be made available for the use of modelcalibration due to the limited financial and labor requrements for data collection.

Field observation data are measured and collected at different times of the day and at various locations on site, which may correspond to various demand loadings and boundary conditions. In order for the model simulation results to closely represent observed data, simulation results must use the same demand loading and boundary conditions as observed data. Thus, the calibration process must be conducted under multiple demand loading and boundary conditions.

Because of the complexity of variations and combinations, the achievements in approximating computed to measured values are limited. However, making minor adjustment to input data, a hydraulic model can be used to accurately simulate pressure and flow rate in the system.

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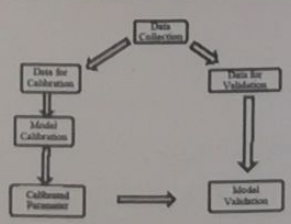


Figure 2-4:Calibration and validation procedure

2.3.3 Water GEMS Model

Water GEMS is one of computer model program developed by Bentley to evaluate the hydraulics analysis and water quality analysis in any distribution system networks. It is a widely used open-structured, public domain hydraulic and water quality model .

One can use it to perform a variety of functions, including steady state and extended period simulations of pressure networks with pumps, pipes, nodes, control valves, reservoirs and storage tanks.

It simulates the pipe flows, node pressures, velocities and head loss in the entire system. After running a system analysis, the results can be viewed on color coded network maps, contour plots, and time series graphs and data tables. The analyses are performed for both the existing state of the systems and for the planned system expansions in future.

Water GEMS V8i provides capabilities, to model and optimize practically any aspect of a distribution system, including the following:

- Perform steady-state analysis for a snapshot view of the system, or an extended-period simulation to see how the system behaves over time.
- Use any common friction method: Hazen-Williams, Darcy-Weisbach, or Manning's methods.
- Control pressure and flow completely by using flexible valve configurations.
- Control pumps, pipes, and valves based on any pressure junction or tank in the distribution system.
- Perform automated fire flow analysis for any set of elements and zones in the network.
- Calibrate your model, manually or use the Darwin Calibrator.
- Develop computer system head curves.

3 Result and Discussion

3.1 Pressure Prediction

The model predicts a maximum pressure of 86 to 107 m of water in 14 out of 49 nodes during peak hour day demand, fig. 3.1. The nodes that have maximum pressure are 28.57% of the total and the rest (69.39%) are subjected to normal pressure. Only 2.04% of nodes have minimum pressure of less than **15m** of water.

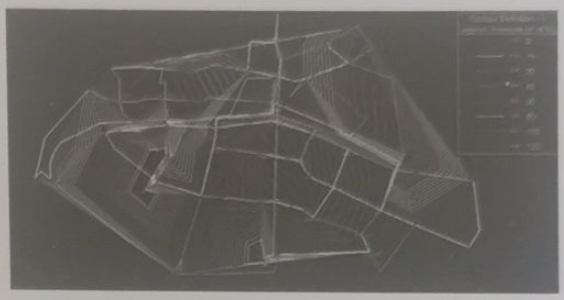


Figure 3-1: Pressure distribution contour at peak hour day demand (8:00 hr.)

The model shows that most of the system minimum pressures are less than 15 m of water during the peak hour day. Figure 3.1 Pressure range from 15 to 107m of water on the west side of the system and decrease to the east with minimum pressures ranging from 14 to 15 m.

Generally, reducing excess pressures in distribution system reduces flow rates from leakages and extends infrastructure working life. The evaluation criteria states that pressures above 15mare desirable.

The model prediction shows: maximum pressure of 92 to 122 m of water in 15 out of 49 nodes during minimum day demand. Thus, 30.6% of the nodes are subjected to maximum pressure. The rest of the nodes (67.35%) have normal pressure. Only one node (2.04%) a minimum pressure of 14 m of water, see figure 3.2.

The excess pressure in distribution system results in increased leakage by 30%.The factor causing the excess pressure in the distribution systems are:

- Topographic constraint (elevation deference of 150 m) in the network system.

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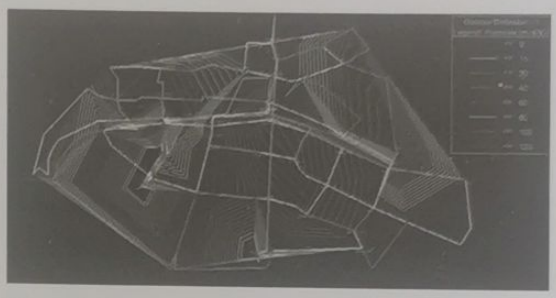


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- Topographic constraint (elevation deference of 150 m) in the network system.

- Direct pumping from the borehole to the existing network system.
- Demand fluctuation at peak day and minimum day demand.
- Lack of enough Sustaining Reducing Valves in the existing network systems.

Minimizing excess pressures in the water distribution system as well as removing transients is desirable. Simple and inexpensive pressure management activities can often lead to considerable reductions in Real Losses. It can be implemented through suitable pressure zoning and DMA management.



Figure 3-2: Pressure distribution by contour at minimum day demand at (1:00hr)

3.2 Velocity and Head loss prediction

Prediction of flow velocity in a pipe is one of th important parameters in hydraulic modeling c water supply distribution and transmission line: Velocity distribution varies with changes in de mand pattern. Prediction during peak hour shows 4.82% of the pipes flows do not satisfy the mini- ire

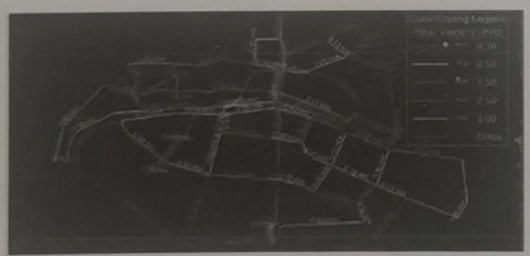


Figure 3-3: Velocity distribution in the pipes at peak hour day demand

To reduce leakage and minor head losses in the pressurized (pumped) system, (pipes 8, 16 and 118 were redesigned) and pipe layout was changed into straight pipe lay out which has less fittings.

3.2 Performance Evaluations

3.2.1 Performance Assessment for Velocity

Based on permissible velocities stated by Walski et al., Thomas , Chase, Donald , Savic, Dragan and TAHAL, 2015, about 4.82% of the distribution network pipes have a low velocity performance of less than 0.05 m/s, (10.84% of pipes), (pipes -1, 9, 11,111, 112,113, 115, 116,117 and 118) have very good velocity performance of (1.5 to 2.78 m/s), about 30.12% of the pipes have good velocity performance of (0.6 to 1.5 m/s) and about 54.22% of the pipes have a satisfactory performance of 0.05 to 0.6 m/s, Figure 3-4.

Based on model output, hydraulic problems associated to velocity are caused by low velocities. On the other hand, the performance assessment related to maximum velocity shows that all the

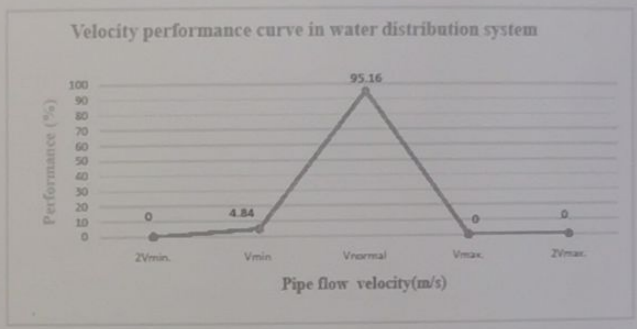


Figure 3-4:Velocity performance curve in distribution system during peak day demand.

3.2.2 Performance Assessment for Pressure

Based on the model output results related to performance evaluation of pressure shows that some distribution systems (J-45, J-40, J-24, J-32, J-43, J-53, J-14, J-25, J-10, J-11, J-27, J-26, J-60, J-39, J-31 and J-9) have a bad performance (both high and low) which indicates hydraulic problems..

Prediction results show(67.35%) of the nodes have a performance of 20 to 80 m pressure, with the exception of junctions J-45 and J-40 that have low performance associated with minimum pressures and Junctions(nodes) J-24, J-53, J-14, J-25,

J-10, J-27, J-26, J-60, J-39, J-31, J-11, J-43, J-32 and J-9 have high performance associated with maximum pressure during a peak day demand (8:00 - 9:00hr),see Figure 3-5.

Some of the junctions (51%) have a low performance (minimum /negative pressure) during a peak-2 day demand (15:00-21:00hr).

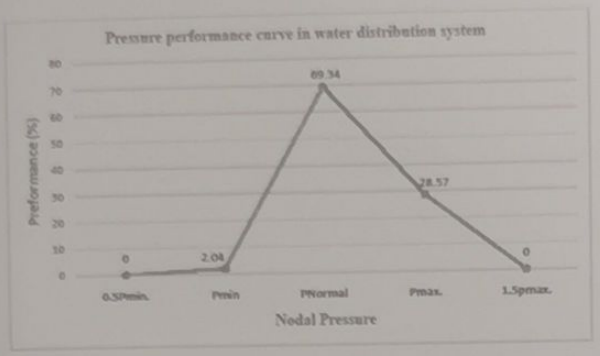


Figure 3-5: Pressure performance curve in water distribution system during peak day demand.

3.2.3 Performance Assessment for head loss

The head loss in about 77.1 % of the pipe length of the network below 5m/km and about 18.07% of pipes length have 5-10 m/km. About 4.82% of pipe length has head losses in the highest class, (above 10 m/km).

4. Conclusions

This research work focused on the analysis of the technical parameters obtained by the hydraulic simulation using the integrated mathematical model. The research includes the technical performance assessment of the analyzed systems. The main conclusions drawn from this research work are:

- Most of the analyzed distribution network (about **53% of** pipes) in the distribution system have velocity below the standard requirement **(0.6 m/s)** during peak hour**.** This is due to the pipe design being carried out for peak load conditions in the next 20-year time. This is one cause of sedimentation problem in the pipe.
- Most of the distribution network systems have excess pressure. This is due to the need to supply water to consumers at higher sections. On the other hand, all distribution network system **(44.89%)** do not satisfy the demand as minimum pressures **(15m)** are not guaranteed in some parts of the system during peak-2-hour consumption **(15:00 pm-23:00pm).**
- Also there is negative pressure causing pipe to collapse. If a gate valve at the top end of a water-filled pipe is closed, water is not prevented from flowing out of the lower end, the resulting negative pressure can make even quite substantial pipes (especially plastic ones) collapse. Another consequence of negative pressure insides a pipe is that water containing pathogens may be sucked into the water supply through any small leaks in the pipe, for example at joints.

In general, it is concluded that the current water distribution network systems of Ginchi town categorized under satisfactory hydraulic performance situation does not supply adequate water to various demand categories of the town. Particularly, the distribution system is not maintaining the minimum and maximum pressure and velocity.

- The existing system consisted of the boreholes, service reservoirs, and pipe system and water points. One borehole is pumped to the distribution network before it delivers to the service reservoir, while water from the other borehole is directly pumped to the service reservoir. Direct type of distribution system has a problem of equitable water distribution system.

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