JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDRAULIC ENGINEERING MASTER OF SCIENCE PROGRAM

HYDRAULIC MODELING OF WATER SUPPLY DISTRIBUTION NETWORK: A CASE STUDY ON DEBRE BIRHAN TOWN, AMHARA REGIONAL STATE, ETHIOPIA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

BY
MAMUSH TEKLE ASSFAW

NOVEMBER, 2016

JIMMA, ETHIOPIA

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NOVEMBER, 2016
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DECLARATION

I, the undersigned, declare that this thesis entitled Hydraulic modeling of water supply distribution network: In case study in Debre Birhan Town is my original work, and has not been presented for a degree in Jimma University or in any other University and that all sources of material used for the thesis has been fully acknowledged.

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This thesis has been submitted for examination with my approval as University supervisor.

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ABSTRACT

Safe and adequate delivery of water to a consumption node is an essential function of water distribution network. However, throughout the world especially in developing countries, the hydraulic performance of water distribution network is inadequate to transfer available water to a consumption node. Debre Birhan Town has been experienced frequent and regular disruption of water because of hydraulic problems related to pressure and velocity during high consumption period and at night time. This study was conducted in Debre Birhan Twon and the aim of the study was to model the existing water distribution system for steady-state and extended period simulation and evaluating hydraulic performance of the system. For conducting this study, both primary and secondary data were collected and software such as waterCADV8i, ArcGIS version9.3, EndeNotex2, and Geographic positioning system Garmin72 (GPS) were used. The study was carried out by selecting pipes having diameter greater or equal to 80 mm in diameter. The simulated result for both steady state and extended period simulation showed that the performance of distribution system related to pressure 24.74% for pressure value (<15m), 74.24% for pressure value (15-60m) and 0.1% for pressure value (>60m) head and the velocity of pipe flow showed that 76.92% for velocity (<0.6m/s),18.18% for velocity range (0.6-2m/s) and 4.89% for velocity (>2m/s). Those problem are resulted from incorrect nodal placement and improper pipe connection during designing the system and when expanding the network to the newly settlement area. The total average per capita consumption of the Town in the year 2015 was 15.62 l/p/d which shows lower performance compared to 20 l/p/d which is set by WHO (2008). The potential of the projected water demand increment in Debre Birhan Town is greater than the current supply potential of water sources. The water demand for the Town of Debre Birhan averagely increases by32.21% every five years up to the year 2030.The performance of the model was evaluated using model evaluation statistics. The value of the coefficient of determination (R^2) for pressure calibration was 0.98.

Keywords: *Extended period simulation, Hydraulic performance, Model, Water distribution network.*

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ACRONYMS

AWRDB	Amara water resource development bureau
CSA	Central statistical agency
DBWSS	Debre Birhan water supply and sewerage office
DN	Distribution network
EPA	Environmental Protection Agency
EPS	Extended period simulation
HC	House connection
GPS	Geographic positioning system
GIS	Geographic information system
MoWR	Ministry of water resource
MDG	Millennium Development goal
OWDSE	Oromia water woks Design and Supervision Enterprise
UAP	Universal Access Program
UNDP	United Nations Development Program
UNICEF	United Nations Children’s Fund
PF	Public fountain
PVC	Polyvinyl chloride
WASH	Water and sanitation hygiene
WHO	World health organization
WSE	Water saving efficiency
WSS	Water supply system
DWT	Dynamic water table
SI	System international
SWT	Static water table
MASL	Meter above sea level
CAD	Computer aided design
YCO	Yard connection on

1 INTRODUCTION

1.1 Background

Next to oxygen: water is essential for human existence (Ermias, 2007). Water is the cradle of life. Without it, no living things can survive in this world. Civilization throughout centuries, were settled near drinking water supply resources. According to Halilsendil (2013), the rivers such as Nile, Tigris and Euphrates were first settlement areas in which human population established their inhabitation on Earth. All the known civilization have flourished with water source as the base and it is true in the present context too. Availability of drinking and provision of sanitation facilities are the basic minimum requirements for healthy living. Safe and adequate delivery of water to a consumption node with permissible pressure and velocity is the primary advantage of water supply distribution network.

The development of water distribution system and analysis method from wood pipe to the modern piping materials, from crude rule of thumb analysis to lengthy long-hand iterative Hardy Cross method to modern Computer Aided design, water distribution networks are designed and constructed to convey treated water from the water treatment plant to the end user (Adeniran and Oyelowo, 2013).

The Environmental Protection Agency (EPA, 2005b), showed that Hardy Cross method of manual iterative, procedure was used throughout the water industry for almost 40 years.

Computer models for analyzing and designing water distribution system have been available since the mid-1960s. Since, then many advances have been made with regard to the sophisticated application of this technology.

Early network models simulated only steady-state hydraulic behavior. In 1970s, modeling capability was expanded to include extended period simulation (EPS) models that accommodate time varying demand and operation. Subsequently, in the early 1980s, investigators began introducing the concept of water quality modeling (EPA, 2005b).

Water distribution systems are Comprising of three primary components; water source, treatment, and distribution network. Water sources can be reservoir, rivers, and ground water wells. The distribution network is responsible for delivering water from the source to its consumers at serviceable pressure and consists of pipes, pumps, junction (node), valves, fittings, and storage tanks (Hopikins, 2012).

Ethiopia is naturally endowed with abundant water resources that help to fulfill domestic requirements, irrigation and hydropower. With its current per-capita fresh water resources estimated at 1924m^3, the country is one of the sub-Saharan African countries endowed with the largest surface fresh water resource. However, 2% of the potential is annually utilized (Ermias, 2007).

As stated by Yehuala (2015), access to safe potable water in Ethiopia in the year 2000 for urban areas was 72 percent, and if Addis Ababa excluded the figure becomes much of worse,38 percent, that is more than 60% of people in urban Ethiopia do not have access to clean drinking water.

Ethiopia has adopted the international millennium declaration. And also the water supply and sanitation united access program (UAP) was ratified the Ethiopian parliament in 2005 and is the current guiding planning framework WASH. The millennium development goal (MDG) target is to attain 70% of national potable water access in 2015 and the millennium development goal (MDG) target urban water supply coverage is to achieve 96% by 2015.

United access program (UAP) national target are much more ambitious than those set under millennium development goal (MDG). It is to attain 98% rural potable water within 1.5 km (15 Liter/capita/day) and 100% of urban potable water within 0.5 km (20 Liter/capita/day) by the end of 2012 (Yehuala,2015). However, this target remains far more ambitious and achievements are still way behind the plans. Rapid urbanization and limited capacity of the public water sector to provide sustainable water supply is at the core of the problem.

According to Yehuala (2015), a number of factors are indicated for marginal water supply and distribution in developing countries like population growth and urbanization, economic development, distribution in efficiency of the water supply systems, inconsistency of the system, climate change (temperature and rainfall variability), topography of the area water loss in distribution system, capacity of nations, towns to manage the water system which would be technological and institutional, inadequate finance and decline of global water resource to improve water supply.

The entire water supply source for Debre Biran Town is ground boreholes which are delivered to a ground storage tank using pumping system.

The rapid growth of population and expansion of factories in the town increases water supply demand and increasing demand for drinking water boosts operation and maintenance costs of existing water supply systems and also obligate water utilities to make new investments for meeting additional demands (Ermias, 2007). The aim of this study is to project the future population and water demand of the town and evaluating hydraulic performance of the distribution system in terms of pressure and pipe flow velocity using waterCAD software.

1.2 Statement of the problem

One of the most important performance indicators in water supply distribution network is availability of optimum pressure at networks head and flow velocity in pipes. The required pressure must be provided at each node, as the performance is mainly judged by the pressure availability in the system. The rates of water use depend on the population served by node; and type of usage (Misirdali, 2003). However, problems in providing satisfactory water supply to the rapidly growing urban population especially that of the developing countries is increasing from time to time. Moreover, managing water at the levels of distribution systems remains one of the major challenges facing many water utilities in most developing countries including Ethiopia (Asmelash, 2014). As a result of overall shortage of water many water utilities have faced a problem in distributing the available water impartially among the residents. To deliver available water to every water consumer's optimum pressure and velocity in distribution system should be maintain to avoid water column separation and to ensure water supply demands at all time. However, pressures in distribution system fail at maximum consumption hour and should not push water to the point of consumption node as well as during night time the consumption decreases and the pressure becomes high.

The deficiency of hydraulic parameter (flow velocity and pressure) occurred due to random connection (placement) for nodes and pipe without any scientific method/mathematical calculation for flow and pressure. Debre Birhan Town has been experienced hydraulic problems resulted from poor estimation of demand and supply relation, intermittent supply which results in hydraulic problem, maintenance costs of existing water supply systems, local operation and management such as peak factors adjustment.

Presently, Debre Birhan Town attracts so many investors and the economic activity of the town increases the population which leads an increasing of water supply demand. This study was undertaken using waterCAD and the existing water distribution network was simulated for both steady sate and extended period simulation analysis to evaluate the performance of the system related to pressure and velocity.

1.3 Objectives

1.3.1 General objective

The general objective of the study is to evaluate hydraulic performance of water supply distribution network in Debre Birhan Town.

1.3.2 Specific objectives

- To evaluate the present water demand and forecast future demand of the town.
- To assess the performance of hydraulic parameters in distribution system.
- To determine the state of the distribution systems in time varying condition.

1.4 Research questions

1. Is the present water supply satisfying the current and future demand of the town?
2. What are the existing problems related to hydraulic parameters in distribution system?
3. How will the water demand vary over the day (24 hours)?

1.5 Scope of the study

The primary objective of the study was to generate the base line information and undergo simulation of existing water distribution network system by running the model for steady-state and extended period simulation analysis to identify system hydraulic performances related to pressure and velocity. Using extended period simulation, the study provides to observe behavior of a modeled system and its response to interventions over time. The optimum pressures and velocities recommended in different literature were used to compare the optimality of nodal pressure and velocity with respect to topographic circumstances, and the size of the network. Therefore the scope of the study is evaluation of hydraulic performance comparing with recommended system design parameters for velocity and pressure.

1.6 Significance of the study

According to Birerley (2006), models are defined as representations of a complex reality. Modeling and simulation are aimed at providing valuable insights in the problem structure instead of giving precise answers. With the advances of this technology, water utilities and engineers have been able to analyze the status and operations of the existing system as well as to investigate the impact of proposed changes.

Therefore, the study provides guidelines concerning water distribution network operation and identify the limitation facing in water distribution network resulted from the deficiency of hydraulic parameter. It helps to give insight for water sector, governmental organization, and NGos for the type of problems existed in water supply distribution network to plan new water project and how to solve those problems for previous water project to meet the need for water to rapidly growing population.

1.7 Limitation of the study

The main limitation faced during the study was availability of documented data which describe all components of distribution systems. Some of data not organized in the office were:

- Organized data in computerized system.
- The division of shape files for each Keble and topography of the town.
- Missed Coordinate (x, y) of the nodes of the system.

Due to the above reason there was some sort of limitation during the preparation of this document.

2 LITERATURE REVIEW

2.1 Water supply distribution networks

Water distribution networks are very important lifeline infrastructure systems, where failures are inevitable. Typical water distribution networks (WDNs) consists of network of pipes, nodes linking the pipes, storage tanks, reservoirs, pumps, additional appurtenances like valves. Water distribution systems represent a major portion of the investment in urban infrastructure and a critical component of public works. The main goal is to design water distribution systems to deliver potable water over spatially extensive areas in required quantities and under satisfactory pressures. Therefore, hydraulic models for water distribution networks have become indispensable tools for understanding system behavior by simulating pressures and flows at different locations and times in the networks (Zyoud, 2003). The design of water distribution systems in general based on the assumption of continuous supply.

2.2 Problems of water distribution system

Water flow is a function of several things, including the size and shape of the opening, and the pressure at the opening (Rossman etal. 2003). Typically, city water supplies are at 40 to 70m, (static pressure). Older private systems are set to maintain water pressure between 20m and 40m, which is too low for some lifestyles; plumbers can set systems higher if the pump is capable of delivering higher pressure (MoWR, 2006).

2.2.1 Water pressure drops due to gravity

Gravity is another source of pressure loss in a residential plumbing system. Energy is required to push the water uphill. For every 0.305m of elevation increase in a pipe, approximately 0.434 m is lost. With no water flowing, the static pressure available at the street main may be 60 psi, but the static pressure at the second floor basin would be 52 m (Ilesenim, 2006).

2.2.2 Water pressure drops due to corrosion

When the water pressure is poor in the distribution system, the most common cause is corroded galvanized steel piping. The common 12.7 mm diameter piping can close down so that the opening is only 3.18 mm diameter or even less. The only solution is to replace this pipe typically with copper. It is wise to replace with a larger diameter pipe on the main feeds at least to improve pressure. When galvanized steel pipe is present, and pressure is low, it is common for accessible pipes running across the basement ceiling to be replace first (Hutton et.al., 2007).

2.2.3 Water pressure drops due to distance from the source

If more water is flowing, the pressure drops more at each point along the pipe (Hutton etal, 2007). The more fixtures flowing at once, the greater the pressure drop at all fixtures and the lower the flow at each fixture (Rossman *et.al.*, 2003).

2.2.4 Other causes of poor water pressure

The supply line from the street to the house may be undersized, damaged or leaking. Long runs of relatively small (13 mm diameter) pipe within a house will result in considerable pressure drop. Clogged pipe within the house will adversely affect pressure. In addition, defective, undersized or poorly adjusted pump will result in poor pressure (Rossman *et.al*., 2003).

2.3 Performance evaluation of urban water distribution system

Performance of a water distribution network can be defined as its ability to deliver a required quantity of water under sufficient pressure and an acceptable level of quality during different normal and abnormal operational situations (Tabesh and Dolatkhahi, 2006). Evaluating the performance of water supply systems is an important for water industry to deliver competent levels of service .A good distribution system should be a capable of supplying water at all intended place within the city with reasonably sufficient pressure head and the requisite amount of water for various types of demand (Garg, 2010). The performance of urban water supply scheme can be evaluate based on four performance measures: Hydraulic, Structural, Water quality and Customers perception

2.3.1 Hydraulic performance

The hydraulic performance of a water distribution system is the ability to provide a reliable water supply at an acceptable level of service that is, meeting all demands placed upon the system with provisions for adequate pressure, fire protection, and reliability of uninterrupted supply (Sharma, 2008). Thus, hydraulic simulation modeling is now a days the most common tool used by water supply engineers and managers as a complement to their experience and insight at the process of establishing a diagnosis, defining the remedies and implementing them (Tabesh *et.al.,* 2011).

2.3.2 Structural (physical) performance

Water mains generally comprise a variety of pipe work and fittings, and which over time are subject to various episodes of augmentation, refurbishment, renewal, replacement, repair and extension. Physical performance of water supply system is the ability of the distribution system to act as a physical barrier that prevents external contamination from affecting the quality of the internal, drinking water supply (Tabesh and Dolatkhahi, 2006).

2.3.3 Customer perception

It is important to maintain the public's confidence in the quality of drinking water and the services provided by a utility. Satisfied customers will pay their bills promptly and will provide political support for necessary rate increases or bond issues. In order to evaluate a WDS, it would be ideal to identify all major customers with their preferences, expectations, needs and requirements and then to explore the ways of meeting their expectations with consideration to associated consequences. Major customers may need those facilities that constitute significant portion of supply demand in a region (e.g., residential, industrial, and firefighting users, public health officials). An ideal approach might be to investigate the quantity of water needed for each individual customer, the period they need water for, and the appropriate level of water quality that is suitable for their need. The estimation of the quantity of water should reflect customer preferences and expectations efficiently. The more closely customer needs are met, the higher the level of satisfaction for customers and the better the water utility is managed (Salmivirata, 2015).

2.4 Methods of water distribution

There are three methods of water distribution system delivered from the source to consumers' house (Zyoud, 2003). These are as follows:

2.4.1 Gravity distribution

This is possible, when the source of water is elevated, so that sufficient pressure can be maintained in the systems. The main important of this method of water distribution system is saving power that needed for pumping.

2.4.2 Distribution by means of pumps with storage

This method used when there is an elevated reservoirs used to maintain the excess water pumped during periods of low consumption, and these stored quantities of water may use during the periods of high consumption

2.4.3 Distribution by pumping without storage

In this method of distribution, water can pumped directly into the main distribution lines without transfer water to service reservoir. The pumping rate should be sufficient to satisfy the demand. An advantage of direct pumping is that a large fire service pump may be used which can run up the pressure to any desired amount permitted by the construction of mains.

2.5 Principles of pipe network hydraulics

In the network of inter connected hydraulic elements, every element is influenced by each of its neighbors; the entire system in such a way that the condition of one element must be consistent with condition of all other element.

Two basic equations that govern in waterCAD modeling network of these inter connections presented by (EPA, 2005a) as follows:

2.5.1 Conservation of mass

The algebraic sum of flow rates in the pipes meeting at a node together with external flows is zero. It assumed that water is incompressible (Hopkins, 2012).

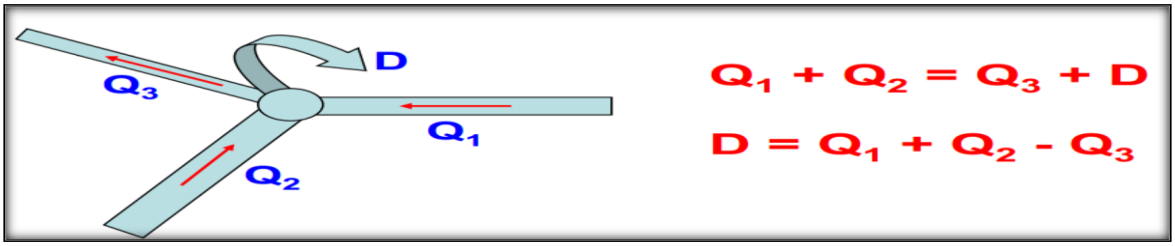


Figure 2. 1 Algebraic sum of flow rates entering and withdrawing from the node (Almasri, 2010).

Where, Q_1 and Q_2 inflows to node, Q_3 = out flows from the node, D = external demand Withdrawn from the node.

2.5.2 Conservation of energy

The energy equation is known as Bernoulli's equation (EPA, 2005a). It consists of the pressure head, elevation head, and velocity head. There may be also energy added to the system (such as by a pump), and energy removed from the system due to friction. The changes in energy are referred to as head gains and head loss.

The principle of conservation of energy states energy neither created nor destroyed. Thus, the energy difference between two points is the same regardless of the path taken. The energy in pipe flow typically described in terms of head. The energy at any point in a distribution system is the sum of three components, pressure head, velocity head, and elevation head.

$$\frac{p_1}{\gamma}+z_1+\frac{v^2_1}{2g}=z_2+\frac{v_2^{\ 2}}{2g}+H_L \tag{2. 1}$$

Where p= the pressure, γ = the specific weight of fluid (Ib/ft^3 or N/m^3), z = the elevation at the centroid (ft or m, v = the fluid velocity *(ft/s* or m/*s),* g = Gravitational acceleration (ft/s^2 or m/s^2 and H_L = the combined head loss (ft or m). There are three forms of energy Pressure head = (p/ɣ), Velocity head = (v^2/2g), and elevation head = z

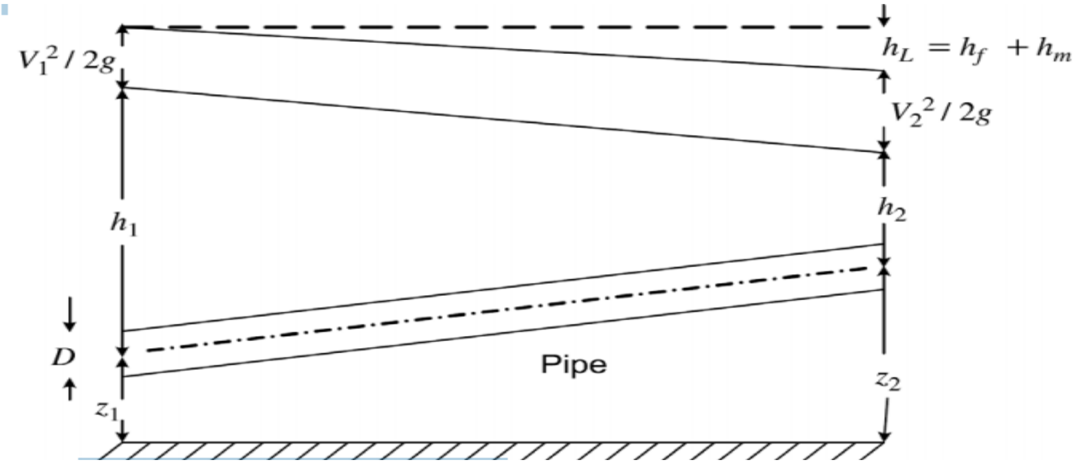


Figure 2. 2 Forms of energy in distribution pipes (Amdework, 2012)

2.6 Head losses

There are different factors that cause the energy losses. The main reason of the energy loss is due to internal friction between fluid particles traveling at different velocities (Zyoud, 2003). There are two forms of resistance which causes energy loss in distribution system.

2.6.1 Surface resistance

Head loss on the account of surface resistance; depend on pipe length, coefficient of surface resistance and friction factor. Surface resistance is characterized as major loss.

2.6.2 Form resistance

The form resistance loss is due to bends, elbows, valves, enlargements, reducers, and so forth categorized as minor loss.

2.6.3 Head loss equations

Hazen – William equation is most frequently used equation in the design and analysis of water distribution networks, it was developed by the experiment and used only for water within temperatures normally experienced in potable water systems(Zyoud, 2003).

Table 2. 1 Head loss equations and area of application Melaku (2015)

Equation	Formula	Area of application
Manning's	$V = \frac{1}{n} R^{2/3} S^{1/2}$	Commonly used for open channel flow
Chezy's (Cutter's)	$V = \sqrt{RS}$	Widely used in sanitary and sewer design and analysis
Hazen-Williams	$V = 0.85CR^{0.63}S^{0.54}$	Commonly used in the design and analysis of pressurized pipe systems
Darcy-Weisbach	$V = \sqrt{\frac{8g}{f} RS}$	Can be used for pressurized pipe systems and open channel flows

The letter symbol in table 2.1 indicates, V= velocity, n= Manning's roughness coefficient, R= hydraulic radius, S= slope, C= Hazen-William roughness coefficient.

2.7 Water hammer

When the velocity of flow in a pipe changes suddenly, surge pressures are generated as some, or all, of the kinetic energy of the fluid is converted to potential energy and stored temporarily via elastic deformation of the system (Zyoud, 2003). As the system rebounds and the fluid returns to its original pressure, the stored potential energy is converted to kinetic energy and a surge pressure wave moves through the system.

Ultimately, the excess energy associated with the wave is dissipated through frictional losses. This phenomenon, generally known as "water hammer", occurs most commonly when valves are opened or closed suddenly, or when pumps are started or stopped. The excess pressures associated with water hammer can be significant under some circumstances.

2.8 Hydraulic design parameters

The main hydraulic parameters in water distribution networks are the pressure and the flow rate, other relevant design factors are the pipe diameters, velocities, and the hydraulic gradients (EPA, 2005b).

2.8.1 Pressure

The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network (Zyoud, 2003)

The minimum pressure should be maintained to avoid water column separation and to ensure that consumers' demands are provided at all times. The maximum pressure constraints results from service performance requirements such fire needs or the pressure bearing capacity of the pipes, also limit the leakage in the distribution system , especially that there is a direct relationship between the high pressure and the increasing of leakage value in the system.

2.8.2 Flow rate

It is the quantity of water passes within a certain time through a certain section. Velocity is directly proportional to the flow rate for a known pipe diameter and a known velocity, the flow rate through a section can be estimated (Amdework, 2015).

Low velocities affect the proper supply and will be undesirable for hygienic reason (Sediment formation may cause due to the longtime of retention).

The effect of the velocity on the diameters circular of pipe system can be observed from the following equation.

$$V = \frac{4Q}{\Pi D^{2}} \qquad 2.\ 1$$

Where D =diameter of pipe, Q = discharge (m^3/s) and V = velocity (m/s). From the above equation it is clear that the velocity increasing should decrease the diameter value. When the velocity increases the head loss increases.

2.9 Simulation

Simulation is the process of imitating the behavior of one system through the functions of another (Amdework, 2012). Simulation can be used to predict system responses under a wide range of conditions without disrupting the actual system.

According to (EPA, 2005a), there are two most basic types of simulation that model may perform, depending on what the modeler is trying to observe or predict. These are steady- state simulation and extended period simulation.

2.9.1 Steady state simulation

A steady state simulation provides information regarding the equilibrium flows, pressures and other variables defining the state of the network for a unique set of hydraulic demands and boundary conditions.

Steady- state models are generally used to analyze specific worst- case conditions such as peak demand times, fire protection usage, and systematic component failures in which the effect of time is not particularly significant.

2.9.2 Extended period simulation

Water CAD can model the behavior of a water distribution system through time using an extended period simulation (EPS). An EPS can be conducted for any duration you specify. System conditions are computed over the given duration at a specified time increment. Some of the types of system behaviors that can be analyzed using an EPS include how tank levels fluctuate, when pumps are running, whether valves are open or closed, and how demands change water CAD user's Guide.

2.10 Urban water demand

Water demand is the volume of water requested by users to satisfy their needs. In a simplified way, it is often considered equal to water consumption, although the two terms conceptually do not have the same meaning (Wallingford, 2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use (Berhe, 2005). Maher and Trifunovic (2013) noted that, water demand is the algebraic sum of the quantity of water utilized by consumer (consumption) and the amount of water physically lost from the system (leakage). It is usually expressed as per capita demand. Per capita water usage varies widely due to the differences in climatic conditions, standard of living, population growth, type of commercial and industrial activity and water pricing. Water demand increases with time due mainly to population growth. Therefore, new water resources ought to be developed in order to meet the increasing water demand at present and in future.

2.10.1 Water demand variations

Water demand in a distribution system fluctuates over time. For example, residential water use on a typical weekday is higher than average in the morning before people go to work, and is usually highest in the evening when residents are preparing dinner, and washing clothes. This variation in demand over time can be modeled using demand patterns. Demand patterns are multipliers that vary with time and are applied to a given base demand, most typically the average daily demand (Vasava, 2007).

2.10.2 Seasonal peak

According to MoWR urban water supply design criterion (2006), towns in Ethiopia are characterized by widely varying climatic conditions and so the variations in consumption during the year, reflected by a peak seasonal factor, will similarly vary. Some consultant have adopted seasonal peak factor of 1.1. The seasonal peak factor adopted for any particular scheme shall be selected according to the particular climatic conditions and existing consumption records (if reliable and unsuppressed). It is expected that seasonal peak factors will vary between 1.0 and 1.2, representing the relatively increase in the average daily demand during the dry and/or hot season months compared with the average annual demand.

2.10.3 Peak day factor

Many communities exhibit a demand cycle that is higher in one day of the week than in others. This situation shall be taken into account by the use of a peak day factor. Some consultants have used peak day demand factors of between 1.0 and 1.3. The value adopted for the design of each individual scheme shall be selected according to judicious observance of the habits of consumers and the knowledge of the community and system operators. It is expected that any value selected for the peak day factor would not fall outside the above range (MoWR, 2006).

According to Amdework (2012), Peaking factors can be determined by dividing the maximum daily usage rate by the average daily usage rate as below

$$p_f = \frac{Q_{max}}{Q_{avg.}} \qquad 2.\,2$$

Where p_f = peaking factor, Q_{max} = maximum daily usage rate and $Q_{avg.}$ = average daily demand Firefighting flows are usually accounted for maximum daily flows. There are several time related demands that should be considered in the model such as seasonal demands, weekly demands population growth and industrial demands. Seasonal demands such as hot dry summers cause increase low watering.

2.11 Source of water for urban water supply

The source of municipal water needs to be adequate and reliable, and many municipalities use more than one type of water source. The source of supply includes surface water, streams, rivers impounding reservoirs and lakes, ground waters and in some instances sea water (Salmivirata, 2015). Ground water is the water found beneath the Earth's surface, being an important water source for many people. According to Salmivirata (2015), approximately $10.5*10^6$ km^3 of ground water, 30.1% of the world's fresh water, is estimated for the entire planet of Earth. Ground water collects naturally through the water cycle forming large pools under surface called aquifers. Ground water can be as deep as several meters, which diminishes the exposure to pollutants.

2.12 Water supply source of Debre Birhan Town

Ground water has been used as source of water for a long period of time. There are ten deep boreholes near the town. The wells are about 70-125m depth are known to exist at Debre Birhan. Seven wells are found at south-east of the town commonly known as Dalecha well field with a total discharging capacity of 52 l/s and four wells are found in the south direction of the town on Beressa area with a total discharging capacity of 45 l/s. On the other hand Beressa River is another source of water used for cloth washing, cattle drinking and it also used as drinking water for the downstream dwellers.

Table 2. 2 Source of water supply for Debre Birhan Town (DBWSS, 2015)

	Designation	Depth (m)	SWT (m)	DWT (m)	Pump Position (m)	Pumping rates (l/s)	Well size (inch)
1	Berssa borehole #4	99	5.3	20.3	56	15	8
2	Beressa borehole #2	92	6.25	11.1	39	15	8
3	Beressa borehole #5	90	8	40	70	15	8
4	Dalecha borehole #1	108	12.79	39.68	83	7	8
5	Dalecha borehole #2	95	11.68	21.39	66	8	8
6	Dalecha borehole #4	125	9.2	35.65	74	5	8
7	Dalecha borehole #6	107	7.4	40	86	10	8
8	Dalecha borehole #7	90	8	40	75	12	8
9	Dalecha borehole Existing#	70	6.66	44.97	60	5	6
10	Dalecha borehole Existing #2	70	6.66	44.97	60	5	6
					Total	97	

2.13 Components of water distribution networks

Water distribution network convey water drawn from the water source or treatment facility, to the point where it is delivered to the users.

2.13.1 Distribution reservoir

Water is collected for use in distribution reservoirs which may be natural or artificial. The primary water sources of water supply system are distribution reservoirs. Dams, water wells and water treatment plant storages are some examples to the distribution reservoirs. Distribution reservoirs store large volumes of water to let the water supply system to run continually.

2.13.2 Storage tanks

Storage tanks are artificial structures that store water and provide water to the system when needed. Equalizing and emergency storage are the two basic task of storage tanks. The variation in flow can be dealt with by operating pumps in parallel and /or building balancing storage in the system. Moreover, in low demand hours when the water consumptions of consumers are almost zero, amount of pumped water is higher than system demand and extra water coming from pumps are stored at storage tank and equilibrium of water distribution system is satisfied again. This equilibrium purpose of storage tank is called as equalizing storage. In addition, storage tanks help water utility to easily manage pressure distribution by preventing pressure fluctuations Emergency storage ability of storage tanks provide required water to perform fire-fighting operations or maintenance operations. For instance, if the pump of distribution network is turned off due to power cut, distribution network continues to serve to the customers by using water stored in the storage tank till the end of power outages (Al-Rayess, 2015).

2.13.3 Pipes

Pipes are the essential elements of a water distribution system. All the elements of water Distribution system, such as junction nodes, pumps, reservoirs, valves and tanks are linked to each other by pipes. Earlier, only limited sizes and types of water supply pipes were available, but nowadays with the help of developing technology, pipes are produced in different materials and sizes to be used in residential and commercial water supply network applications (Kaychamber, 2004).

2.13.3.1 Pipe length

The length assigned to a pipe should represent the full distance that water flows from one node to the next, not necessarily the straight- line distance between the nodes of the pipe. Scaled versus schematic length. Most simulation software enables the user to indicate either a scaled length or a use-defined length for pipes. Scaled length are automatically determined by the software, or scaled from the alignment along the electronic background map. User-defined lengths, applied when scaled electronic maps are not available, require the user enter pipe length. Even in some scaled models, there may be areas where there are simply too many nodes in close proximity to work with them easily at the model scale (such as at a pump station) (Newbold, 2009). In this case, the modeler may want selectively the portion of the system schematically.

2.13.3.2 Pipe diameter

A pipe's nominal diameter refers to its common name, such as a 4 inch (100 millimeter) pipe. The pipe's internal diameter, the distance from one inner wall of the pipe to the opposite wall may differ from the nominal diameter because of manufacturing standards. Most new pipes have internal diameter that are actually larger than the nominal diameter.

2.13.4 Pumps

A pump is an element that adds energy to the system in the form an increased hydraulic grade. Since water flows "downhill" (that is, from higher energy to lower energy), pumps

are used to boost the head at desired locations to overcome piping head loses and physical elevation difference (Kaychamber, 2004).

A three point pump curve can be developed based on our static and hydrant tests, a range of demand and/or tank levels in the proposed system. The formulae can be used to develop a 3-pont pump curve (Kaychamper, 2004).

$$Q_o = Q_t\left(\frac{p_s - p_o}{p_s - p_t}\right)^{0.5} \qquad 2.\ 3$$

Where Q_o = Flow available at the chosen pressure (m^3/s), Q_t= Residual flow during hydrant test (m^3/s), p_S= Static pressure during hydrant test (kpa), p_o= Chosen pressure, at which Q_O is to be calculated (psi, kpa), p_t =Residual pressure during hydrant test (psi, kpa).

2.13.5 Valves

In a water supply system, valves are the major component to control the flow of water. By operating the valve the flow can be controlled in different ways. Completely preventing water flow, adjusting the amount of water flow, directing flow to different paths and reducing flowing water pressure are some capabilities of valves in water supply system. Valves may be operated manually, either by a handle, lever or wheel.

Valves may also be operated automatically by electronic devices and may be operated remotely (Newbold, 2009).

2.13.6 Fire hydrants

A fire hydrant is an essential element of water distribution network to provide required water for fire-fighting. In fire-fighting operation, pressure and flow of water are important factors while extinguishing fire hydrants are designed to provide required high water pressure and flow. Therefore, fire hydrants are connected to the distribution network with pipe having larger diameters to provide excessive water flow required for fire-fighting (Almasri, 2010).

2.13.7 Junctions

The primary function of junction node is to provide a location for two or more pipes to meet. The other is to provide a location to withdraw water demand from the system or inject inflows (sometimes refers to as negative demands) into the system.

Junction demands typically do not directly relate to real-world components since pipes are usually joined with fittings, and flows are extracted from the system at any number of customer connections along a pipe (Al-Rayess, 2015).

3 RESEARCH METHOD AND MATERIALS

3.1 Description of the study area

The Town of Debre Birhan is located at $9^{o}41^{'}$N latitude and $39^{o}31^{'}$E longitude. It is found at a distance of 130 km from Addis Ababa the capital city of Ethiopia on the paved highway to Dessie and Mekele in the Amhara regional state, north shoa Administrative zone. It is situated on plateau in the central Ethiopia highland system about 15 km west of the great rift escarpment at an average elevation of 2840 m.a.s.l (Ermias, 2007).

The area of Debre Birhan Town is 14.71 km^2 (5.68.sq.mill). From the elevation it belongs to the Dega climatic zone. The mean annual temperature ranges between 5^{o}C to 23^{o}C and the mean annual rainfall is 844 mm (Ermias, 2007).

The population of the town become increasing from time to time in relation with the town development in investment, trade and other activities. According to the population census of 2007 by CSA, the population of the town is estimated to be 110,408 with a density of 7,500/km^2. The people of the town are mainly practicing trade and the surrounding population also living with farming activities. The town is administratively divided into nine administrative units (locally known as Kebeles).

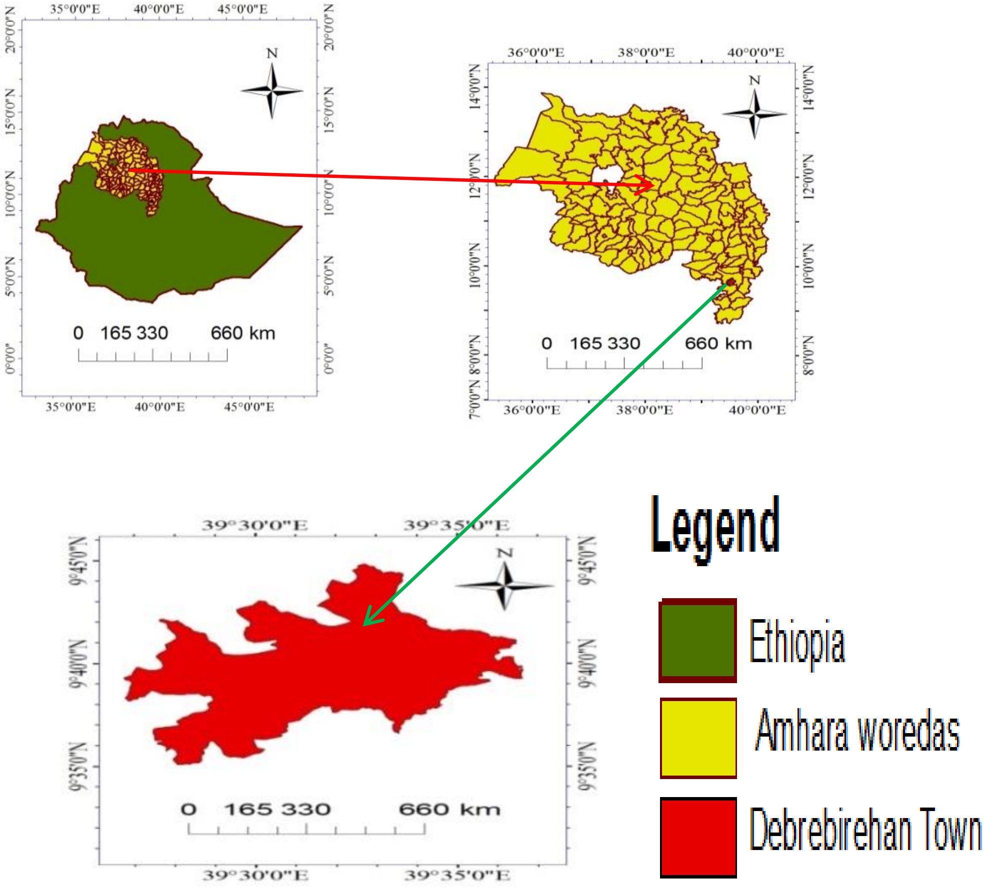


Figure 3. 1 Location map of the study area (ArcGIS version9.3).

3.2 Study variables

The study variables considered for this study were both dependent and independent variables.

Independent variables are more related with the specific objectives. Independent variables can alter (affect) the dependent variables. The variables which cause significant effect on the dependent variables were:

- Elevation
- Pipe roughness
- Pipe size (diameter)

As the elevation increases the pressure decreases which cause high pressure zone. The size (diameter) of a pipe can affect the model significantly. Using proper pipe diameter used to meet peak demand and fire protection while maintaining an adequate dynamic pressure in the system. A large diameter pipe has a low velocity.

Dependent variables can be observed and measured to determine the effect of the independent variables which was directly related to the general objectives.

- Hydraulic performance (velocity and pressure) in the distribution system.
- Nodal demand

3.3 Data collection process

The data collection process was performed using both primary and secondary data collection techniques to get the required information.

3.3.1 Primary data collection

The data was collected on field survey by observation and measuring. GPS Garmin 72 was used in locating the latitude and longitude of the selected main node of the system. From field survey missed x and y coordinates of nodes are collected. The pressure for ten sample nodes (J-30, J-28, J-22, J-17, J-38, J-37, J-18, J-48, J-40, and J-114A) was measured near the corresponding location using pressure gauge.

3.3.2 Secondary data collection

Existing available data describing the system have been gathered from different concerned organization. From Debre Birhan Town water supply and sewerage office the following data has been collected.

- Water production and consumption
- Water supply distribution network drawing

The water supply network drawing has the following system information:

- ✓ The elevation of the distribution system.
- ✓ System map of water distribution network. The water distribution network is available on the system drawing having the following data
- ▪ Water distribution network layout.
- ▪ Pipe data like material type, size and length, tanks and valves in the network presented in appendix AB.

From last population and housing census report (CSA, 2007), the growth rates and population for Debre Birhan Town has been collected in order to forecast the future population.

3.4 Source of water for Debre Birhan Town

The water supply source of entire town is ground water sources from two areas of deep boreholes. Seven wells are found on Dalecha area in the south east direction of the town and three wells are found on Beresa area in the south direction of the town.

Table 3. 1 Wells and their daily water production (DBWSS, 2015).

No	Name of wells	Discharge (l/s)	Daily working hour (hr.)	Daily water production (m^3/day)
	Dalecha boreholes			
1	Dalecha borehole #1	7	19	479
2	Dalecha borehole #2	8	19	547
3	Dalecha borehole #4	5	19	342
4	Dalecha borehole #6	10	19	684
5	Dalecha borehole #7	12	19	821
6	Dalecha existing borehole #1	5	19	342
7	Dalecha existing borehole #2	5	19	342
8	Beresa borehole #4	15	19	1026
9	Beresa borehole #2	15	19	1026
10	Beresa borehole #5	15	19	1026
Total		45		3078
Sum total				6635

As shown in table 3.1, the total daily water production of the wells was calculated by multiplying the discharging capacity of wells by pump operating hours (19) hours a day.

3.5 Existing distribution systems

Existing data describing the system has been gathered to generate the system water distribution model.

3.5.1 Water distributing pipes.

Pipes are the essential elements of a water distribution system. All the elements of distribution system, such as junction (nodes), pumps, reservoirs, valves and tanks are linked to each other by pipes (Melaku, 2015).

Table 3. 2 Pipe diameter and corresponding length used as software inputs (DBWSS, 2015).

Diameter (mm)	Length steel (m)	Length PVC (m)
80		6,880
90		1,275
100		4,699
110		4,558
150	3641	
200	6776	
250	4,084	
300	4,383	
350	570	
Total	19,454	26,579

Skeletonization is the process of selecting for inclusion in the model for enabling quicker calculation (OWDSE, 2010). Using skeletonization pipes having diameter greater or equal to 80mm were selected for modeling the distribution system. As indicated in table 3.2, a total length of 19,454 m from steel pipe and a total length of 26,579 m from polyvinyl chloride (PVC) pipes have been used in the model.

3.5.2 Storage tank

Storage tank is a structure used to store water and provide water to the system when needed. Storage tank is crucial to continuously supply during a pump turned off and equalize water during peak demand hours. The study area has two storage tanks which functions for storing water and equalizing flow to each service area. The municipality uses these storage tanks as a pressure zone boundary based on the topography to manage the distribution.

Table 3. 3 Location and capacity of existing storage tanks (DBWSS, 2015).

Designation of tank	Elevation (m)	X (m)	Y (m)	Diameter (m)	Capacity ($m^{3)}$
T-1	2846	557,050.64	1,070,373.81	20	2000
T-2	2875	557,987.20	1,067,962.62	16	1000

3.6 Population projection

The future population of Debre Birhan town was projected using geometric increase method. The geometric increase method is mostly applicable for growing towns and cities having vast scope of expansion. It is based on the assumption that the percentage increase remains constant. The following formula has been applied for population projection (Amdework, 2015):

$$P_n = P_o(1+r)^n \qquad 4.1$$

Where P_n = population, P_o = population at n decades or year, n = decade or year, r = rate (percent increase)

3.7 Base year population

The base year population was available from the 2007 population and housing census of Ethiopia, published by the Central Statistical Agency (CSA, 2007).

3.8 Water supply coverage analysis

The coverage of water supply for the town has been evaluated based on the average per capita consumption and by mode of service. Water demand is the daily water requirement for use by human being for different domestic purposes. The annual total volume of water consumed for domestic purpose has been converted to average daily per capita consumption using the total number of population (AWRDB, 2012).

$$\text{Per capita consumption (l/p/d)} = \frac{Annual\ consumption\ (m^3)*1000\ {}^{l}/_{m^3}}{Total\ population\ of\ the\ town*365} \qquad 4.2$$

3.9 Projection of per capita water demand by mode of services

Per capita demand of the town was projected by mode of services using Amahara water supply design criteria (2012).

Table 3. 4 Base per capita water demand by mode of service (AWRDB, 2012)

Mode of services	Per capita demand
House connection (HC)	59.8
Yard connection on (YCO)	33.31
Public fountain users (PFU)	23.53

The value was given for the year 2012 to convert to 2015 (base year) the annual growth rate of 2 % for public tab users, 3% for yard and house connection. From the total adjusted demand, 10% for institutional and commercial demand, 10% for industrial water demand and 5% for firefighting water demand were added to get the average daily water demand. To get the projected water demand 25% of average daily water demand was added.

3.9.1 Water demand variation

The daily and hourly water demand varies in a community area. The daily water demand in a community area vary during the year due to seasonal climate patterns, the work situation and other factors, such as cultural or religious occasions. The hourly variation in domestic water demand during the day is much greater. Two peak periods can be observed: one in the morning and one late in the afternoon (MoWR, 2006).

The peak factor (k_1) for the daily water demand was taken as 1.2. The peak hour demand was calculated by multiplying average hourly demand by the hourly peak factor (k_2). The factor (k_2) is chosen in the range 1.5-2.5 where a pipe connection designed to supply a small group of consumers, a high value should be adopted because of the effect of instantaneous demand for this study the value of factor (k_2) was taken 1.6. The peak demand was calculated as $(k_1)*(k_2)$*average hourly demand.

3.10 Materials used to the study

- Bentley waterCADV8i
- GPS Garmin72
- ArcGIS version9.3
- EndNote program
- Pressure gauge

Bentley waterCADV8i was used to model the behavior of water distribution systems. Bentley water CAD has a capability of modeling water distribution behavior at steady-state and time varying situation.

To analyze and evaluate hydraulic performance of the existing water distribution system, a model was developed using Bentley water CAD V8i. Bentley water CAD V8i is selected for this study because of the following reason:

- It is aided with good quality of manual.
- Its integration with external software, like Auto CAD and Microsoft excel.
- It requires less effort and shorter time to build a model than others do.

GPS Garmin 72: Adjusted GPS was used to gather the geographic coordinate system of the distribution network. GPS has an ability to locate the latitude and longitude of the system on the ground by receiving satellite information.

ArcGIS version 9.3 was used to delineate the study area.

Endnote program: used to place citation and references in the document.

Pressure gauge: Pressure gauge was used to measure the pressure of water in selected area of distribution system.

3.10.1 Modeling process

The modeling was performed using the following steps:

1. Input data arrangement.
2. Initial setup (the unit is set to SI unit)
3. Network schematic.
4. Model building.
5. Problems analysis
6. Model calibration and validation

3.10.2 Model representation

System distribution networks are drawn as a combination of various system components. The model is commonly, in water distribution system represented by system elements, such as reservoir, tank, pipe, node, pump and valves.

3.11 Data entering technique

The input data should be entered into the software using the properties editor for each element by individually opening the properties editor. However, it is better to enter data for similar elements using flex table so that the data was entered to the operating software using flex table.

3.11.1 Hydraulic calculation

Water CAD program solves for the distribution of flows and hydraulic grades using the energy equations. The quantities can be used to express the head loss or head gain between two locations. The conservation of energy principles states that the head loss through the system must balance at each point. Head loss between any two nodes must be sign consistent with the assumed flow direction. Any internationally recognized formula may use in the hydraulic computations.

The study was conducted using Hazen-Williams equation as it is commonly used in the design and analysis of pressurized pipe systems.

The coefficient (C-value) 150 for polyvinyl chloride (PVC) pipe and 140 for steel pipe for Hazen-William formulae was chosen.

3.12 Nodal demand calculation

Bentley Water CAD V8i enables to allocate demand to the model of water distribution system. Load Builder greatly facilitates the tasks of demand allocation and projection. In this study the nodal demand was allocated using unit line demand allocation method.

Demand for each node was calculated and analyzed based on the number of inhabitants for each consumption node, and the period of supplying water to calculate the peak factor of demand for each node. Population around the node was counted, and the people served by the node were multiplied by per capita demand. Nodal demand is calculated using the following formulae:

$$N_d = \sum p_i d_j \qquad 4.\ 3$$

Where N_d = nodal demand, p_i = population supplied by the nearest node of the service area, d_j = per capita demand assigned for the study area, i = subscript referring to the i^{-th} node in the service area, j = subscript referring to the j^{-th} pressure zone in the service area.

3.13 Water distribution system network

A water distribution system is a pipe network that delivers water from single or multiple supply sources to consumers. There is a general belief arising out of negligence on behalf of service providers, that water supply networks can be expanded indefinitely. Many water supply providers, in a drive to provide wide water supply coverage increase the number of customer connection through a massive network expansion. Because of rapid population growth and existence of unacceptable pressure and velocity in the distribution network water demand exceeds available production capacity.

The flow and pressure distributions across a network are affected by the arrangement and sizes of the pipes and the distribution of the demand flows. Since a change of diameter in one pipe length will affect the flow and pressure distribution everywhere, network simulation is not an explicit process. Pipe network analysis involves the determination of the pipe flows and pressure heads that satisfy the continuity and energy conservation equations.

3.13.1 Pressure in distribution system

The pressure at node depends on the adopted minimum and maximum pressure within the network, topographic circumstances, and the size of the network. The static pressure in the distribution piping system is the pressure head with no water flowing in the network is equal to the height to which the column of liquid could be raise.

According to Swamee (2008), nodal pressure is stated as the minimum design pressure to discharge design flows on to the systems. It is based on the population served, types of dwellings in the area, and firefighting requirements.

The general consideration is the water should reach up to the upper stories of low-rise buildings in sufficient quantity and pressure, considering firefighting requirements. In case of high- rise buildings, booster pumps are installed in the water supply system to water for pressure head requirements.

The MoWR water supply design criteria (2006) recommended the pressure range in distribution system to be 15-60m water head. However, there is no defined maximum and minimum pressure ranges set by the office, regarding to this literature based recommendation for optimum operating pressure was used to asses system hydraulic performances.

- ✓ The minimum static pressure at peak hour demand 30m of water column (30mwc) would be required to serve up to three stories high.

- ✓ Maximum static pressure during low demand periods was limited to 60m of water column (60mwc).
- ✓ Minimum dynamic head was established at 15 m meter of water column (15mwc)

3.13.2 Pipe velocity in water supply network

Different design guide line has been developed by different scholars for the standard velocity in pipe flows. They recommended optimum velocities for pipe flow in transfer and distribution mains are presented in table 3.5.

Table 3. 5 Pipe velocity range given by different organization

Distribution type	MoWR (2006)	Worldbank (2012)	OWDSE (2010)
Maximum transfer main velocity	2 m/s	3 m/s	2.5 m/s
Maximum velocity in distribution	2m/s	1.5 m/s	0.8 -1.2 m/s
Minimum velocity in distribution	0.6 m/s	0.4 m/s	0.5 m/s

Although the design guide line centered the same idea, the study was conducted using velocity standards given by MoWR water supply design criteria (2006) because of it work at country level.

3.14 Model calibration and validation

Once the first simulation run is completed the immediate concern is whether the results match the reality. Several runs have to be executed to confirm that:

1. The model gives a logical response to any altering input data (model validation)
2. The model's behavior corresponds to the reality (model calibration)

For model calibration and validation effort data were collected from field visit. Calibration data includes: nodal elevation, pipe diameter (pipe size), material types. For this study pipe roughness was taken as model parameter to be adjusted.

Model accuracy can be evaluated using pressure criteria. Lingereddy (1997) showed that the most common criteria are absolute pressure difference or relative pressure difference. In most cases relative pressure difference criteria is preferred.

3.14.1 Acceptable level of calibration:

The acceptable level of pressure criteria has been presented by Lingireddy (1997) as follows:

1. 85% of field test measurements should be within ±0.5m or ±5% of the maximum head loss across the system, whichever is greater.
2. 95% of field test measurements should be within ±0.75m or ±7.5% of the maximum head loss across the system whichever is greater.
3. 100% of field test measurements should be within ±2m or ±15% of the maximum head loss across the system, whichever is greater.

Sampling sites

The water supply office of the town uses two pressure zones for the sake of water distribution management. Based on the pressure zones ten representative sample nodes were selected for calibration.

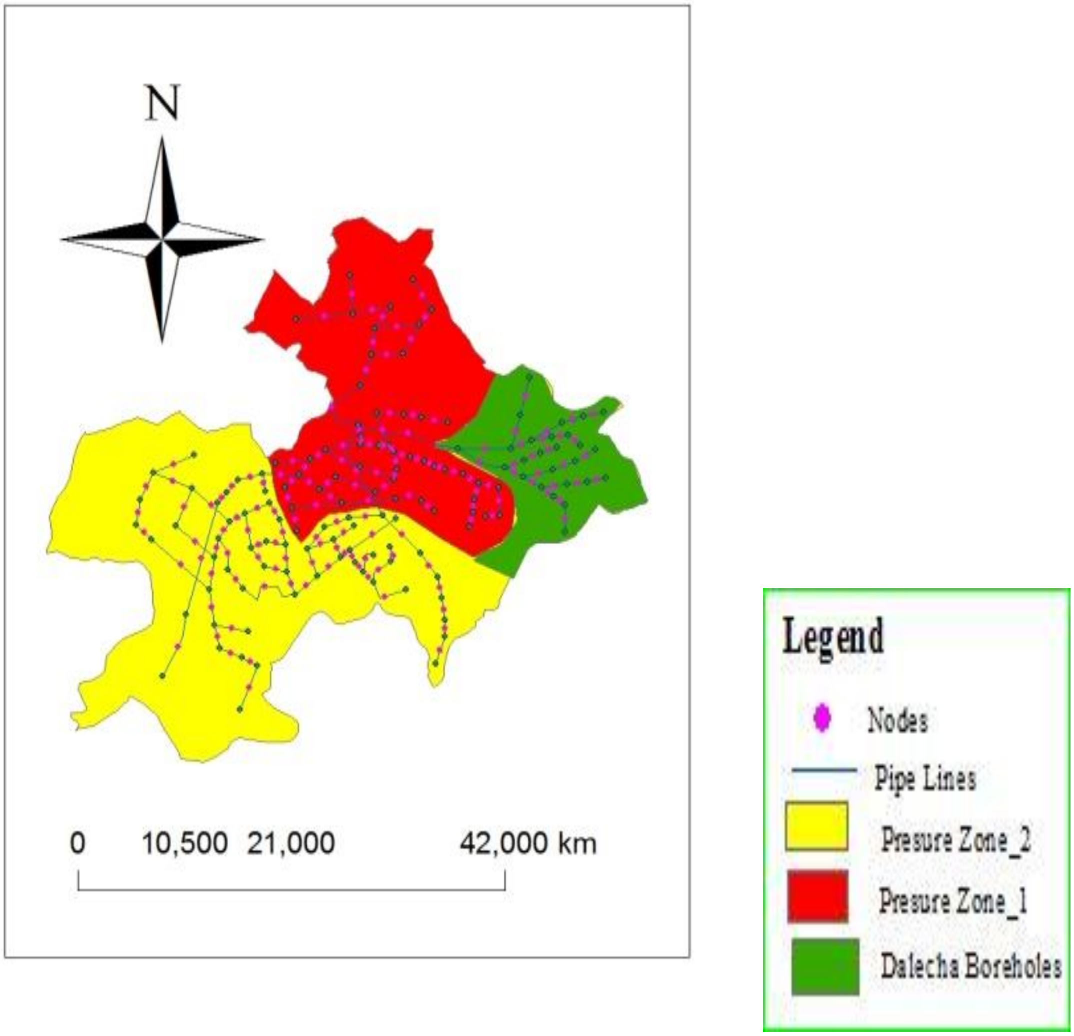


Figure 3. 2 Location of pressure zones

As shown in figure 3.2, pressure zone one is the location of storage tank one and pressure zone two is the location of storage tank two. Pressure zone-1 is high pressure zone with high elevation relative to pressure zone-2. Based on the pressure zones the sample nodes were selected which provide high degree of information amenable to sampling sites.

4 RESULTS AND DISCUSSIONS

4.1 Water sources and production

The main source of water supply for the entire town is ground water sources from two areas of deep boreholes. Seven wells are found on Dalecha area in the south east direction of the town with a total discharge capacity of 52 l/s and three wells are found on Beresa area in the south direction of the town with a total discharge capacity of 45 l/s. According to the information found during discussion with the experts of water supply and sewerage office no other sources of water for potable drinking water except the wells.

Table 4. 1 Wells working with electric power and generators.

Wells condition	Wells working with electric power	Wells with stand by generator
Number of wells	10	5
Total discharge (l/s)	97	52
Daily working hours	19	19
Daily production (m^3/day)	6635	3357

As shown in table 4.1, the supply of water to the town is hundred percent dependent on electric power. When electric power working (19 hours), the wells produces a total volume of discharge 97 l/s which is equal to 77 l/s in 24 hours. Therefore the total volume of water entered to the storage tank within 24 hours is 6635 m^3. When the electric power is stop working the supply from 5 wells stop and only 5 wells which have stand by generators start to operate so that the daily production of water decreases by 49.4%. During this condition shortage of water supply occurred to satisfy the demand of the town. The total production of water recorded by the office of water in the year 2015 was 932479m^3 and the total billed consumption of the town was 886368m^3.

The amount of total consumed water is less than the amount of water supplied. The difference between the amount of supplied water and the amount of total consumed water gives total loss. Therefore, the total loss of water in the town for the year was 932479m^3-886368m^3 which gives 46111m^3.

4.2 Population forecasting

In order to forecast the population of the study area in 2015 based on last population census report the population and housing census report of 2007which was prepared by Ethiopian Central Statistical Agency have been used. The growth rates 4.3% which was reported by CSA for Debre Birhan Town was used for the current population projection.

Table 4. 2 Population growth rates for the town of Debre Birhan (CSA, 2007).

Years	Growth rate
2005-2010	4.5
2010-2015	4.3
2015-2020	4.1
2020-2025	4
2025-2030	3.8

Applying the geometric population projection method the population of Debre Birhan has been projected up to year 2030.

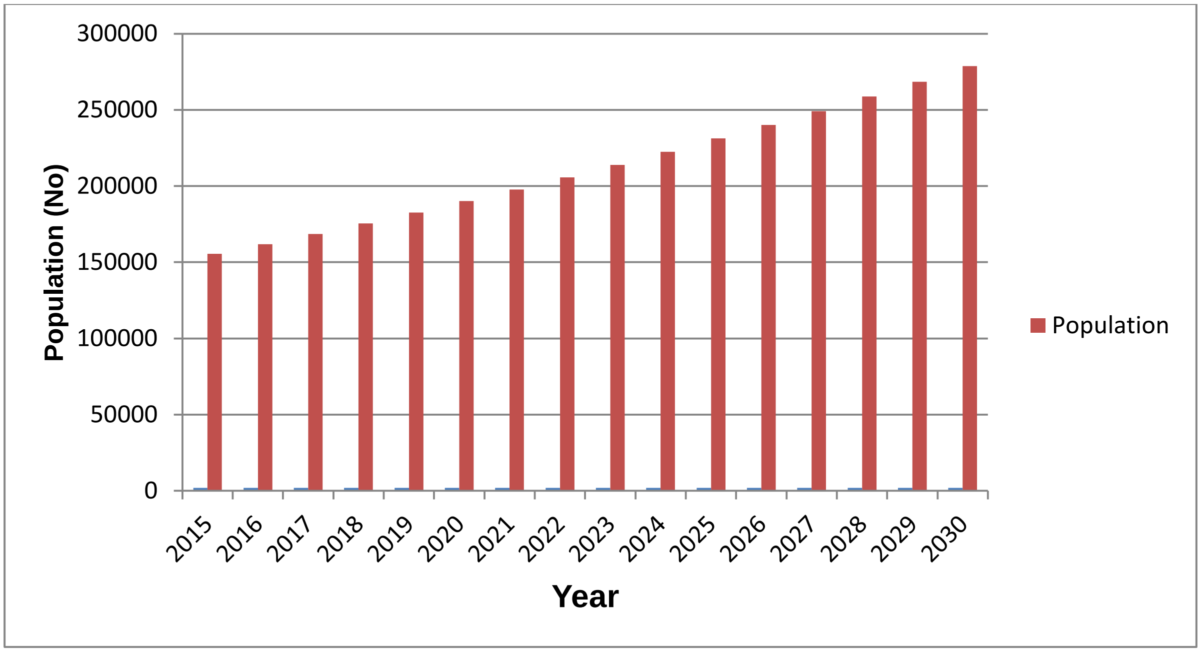


Figure 4. 1 Projected Population of Debre Birhan Town (2015-2030)

4.3 Demand projection by mode of services

Using per capita per day water demand, the percentage of population served by house connection (HC), yard connection (YC), and public fountain (PF) has been estimated for each respective year (2015-2030). The total domestic demand is then found by multiplying the per capita per day demand with population served by each mode of service. The rate of percentage for per capita demand projection for each mode of service was performed based on the guideline presented by Amhara water resource development bureau (AWRDB, 2012). Based on the guideline, the growth rate of water demand for each of service assumed is 3% per annum for house and yard connection users and 2% per annum for public tap users was used.

Table 4. 3 Population projection by mode of service.

		Year			
Population/Service Levels	Unit	2015	2020	2025	2030
Population	No	155,515	190,119	231308	278,726
Percentage of Population					
Served by:-					
HC	%	13.38	16	18.48	21.42
YC	%	41.84	48.5	56.23	65.19
PF	%	44.33	35.5	25.29	13.39
Per Capita Demand					
HC	Lpcd	65.5	75.9	88	102
YC	Lpcd	36.5	42.31	49.05	56.87
PF	Lpcd	25	27.6	30.47	33.65
Demand by Service Standard					
HC	m^3/d	1408	2309	3,712	6090
YC	m^3/d	2375	3901	6,380	10333
PF	m^3/d	1724	1863	1782	1256
Total water demand	m^3/d	5507	8073	11,874	17679

The socio- economic and climatic adjustment factor was combined 1.05*0.9= 0.945 used to calculate the adjusted water demand by multiplying the total water demand for respective years. Using 10% for institutional and commercial demand, 10% for industrial water demand, 5% for firefighting demand from the adjusted water demand the average daily water demand was calculated. Taking 25% for unaccounted water demand from average daily water demand the projected water demand was calculated. The maximum daily water demand and peak hour demand was projected using the maximum day factor of 1.2 for maximum day factor and 1.6 for peak hour factor which is recommended for towns having population greater than 80000 (AWRDB,2012). The detailed result of the projected population and water demand is presented in appendix (4).

4.4 Average per capita daily water demand

Water demand is a summation of all consumptions given in the preceding sections and will determine the capacity needed from the sources. Under constrained resources, water is allocated to consumers and the actual water supply may not be able to meet the demand. The total annual recorded consumption of the town has been converted to average daily per capita consumption using the number of population for the year 2015.

Table 4. 4 Daily per capita consumption (l/c/day) from billed consumption of 2015.

Year	Population	Annual billed consumption (m^3)	Per-capita consumption (l/person/day)
2015	155515	886368	15.62

As indicated in the table 4.4, the total average daily per capita consumption of the town is 15.62 l/p/d. The average per capita consumption is very low compared to the value set by WHO (2008) which is 20 l/p/d within a radius of o.5km.

4.5 Distribution network modeling

Water distribution network modeling provides a fast and efficient way of predicting the network behavior, calculating pipe flows, velocities, head-loss, pressure and tank levels.

4.5.1 Model representation

Network data describes all physical components of the water distribution system and defines how those elements are interconnected. Distribution system networks are drown as a combination of various system components. It commonly includes; reservoir, pipe, tank, pumps and valves. With little difference the real water distribution system represented as a combination of nodes and links. Junctions, reservoir and tanks usually represented as nods. Pipes, Pumps and valves represented as links.

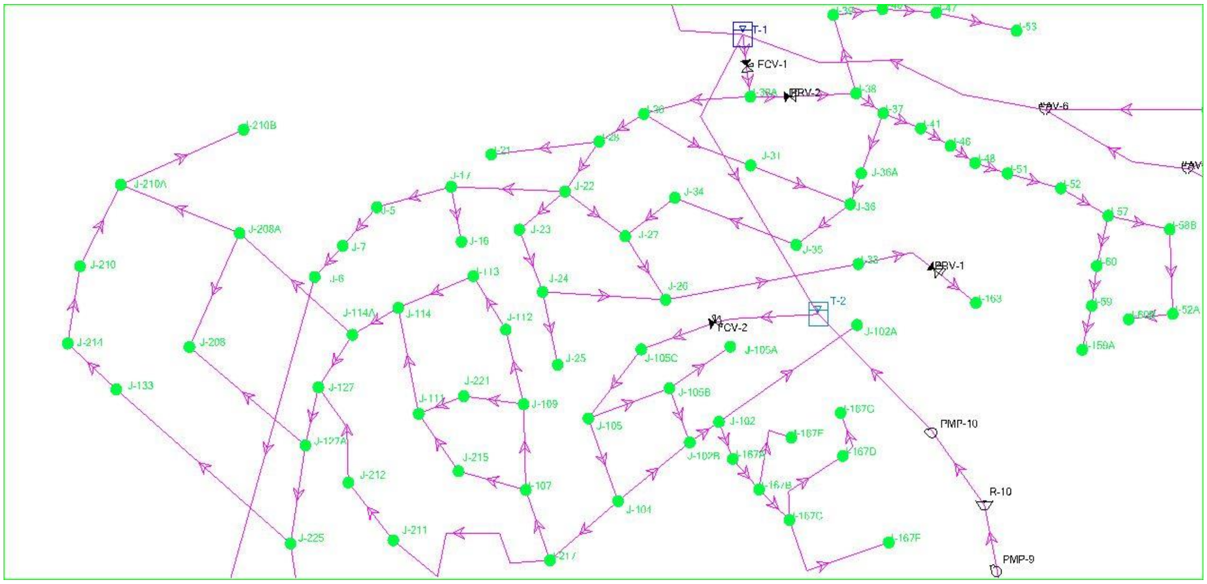


Figure 4. 2 Layout of water distribution network

Figure 4.2, shows the layout of water distribution network representation which includes pipe, junction (node), valves storage tanks, reservoirs (wells) and pumps.

Table 4. 5 Length of pipe and their coverage used for modeling.

Diameter (mm)	Material	Length (m)	Coverage (%)
80	PVC	6880	14.95
90	PVC	1275	2.77
100	PVC	4699	10.21
110	PVC	4558	9.9
150	Steel	3641	7.91
200	Steel	6776	14.72
250	Steel	4,084	8.87
300	Steel	4,383	9.52
350	Steel	570	1.24
Total		46033	

As described in table 4.5, the total length of pipes represented in the model steel covers 42.3% and polyvinyl chloride (PVC) covers 57.7%. In the model different diameter pipes are represented to contribute their function to water distribution network. In the model 80 mm and 200 mm pipes are used in high percentage compared to other diameter represented in the model.

Table 4. 6 Summary of water distribution network elements

System components	Number of element represented
Junction	97
Pipes	143
Tank	2
Pump	10
Reservoir (wells)	10
Pressure sustaining valve	6
Flow control valve	2
Air valve	5

The system elements are organized for the purpose of modeling the distribution network. As shown in table 4.6, pipe networks consists of junctions, tanks, reservoirs, regulating valves and pumps.

4.6 Simulation analysis

Water CAD is capable of performing two types of simulations, steady-state and extended period simulation.

Analysis of the model of existing systems has been done by running the model at current year daily average at peaking and temporal variation of demand with different scenarios.

4.6.1 Steady state simulation analysis

The model has been performed in steady state simulation analysis for the average daily demand, which is the demand at every node not changing throughout 24 hours of a day. It is required to run single period at the beginning of the simulation as to observe the model under snap shot situation. The simulated result is presented in Appendix (1)

4.6.2 Extended-Period simulation analysis

The system condition have been computed over 24 hours with a specified time increment of three hour and starting model run at time 12:00 PM. The software simulates dynamic state hydraulic calculation based on mass and energy conservation principle. The model has been simulated for every two-hour time setup in the twenty- four hour duration. However, for the analysis the peak and minimum hours demand has been simulated to identify the current performance of the system related to system parameter like pressure and velocity.

The model has been performed 12:00 PM to 3: 00 AM for minimum hour consumption and 6: AM to 8:00 AM for the peak hour consumption. It is noted that minimum hour model run has been made at 1:00 hour from starting time and peak hour model has been made at 7:00 from the starting. The dynamic simulated results have been presented in Appendix (2).

4.7 Hydraulic parameters in water supply distribution network

4.7.1 Pressure

Pressure in water distribution systems has to be maintained optimum; as to efficiently make water available to each demand category including at instances of firefighting (high withdrawal period) and as to reduce leakage as well as pipe breakage across the system.

Swammee (2008) described that the minimum design nodal pressure is the pressure assigned to discharge flow on to the system.

At low peaks through night hours the pressure in the system becomes high and the leakage loses expected to increase whereas at high peaks the pressure becomes small and the leakage losses expected to decrease

When the pressure exceeds the elevation of the storage tank, water can start to fill the storage tank. The higher the pressure is more water start to enter to the tank. In this study, the model run from the input of existing data a total node of 97 was reported from the project inventory dialog box. The results show that 25 nodes from a total 97 nodes have been observed out of the recommended serviceable pressure (15mH2o to 60 mH2o).

The steady state analysis describes the behavior of the system at a specific point in time with flow rate and hydraulic grade remains constant over time. Extended period simulation indicates the performance of the distribution system better than steady state simulation during high consumption or at stress condition.

The simulated result for extended period simulation at junctions (65, 66 and 72) showed that changes from positive pressure to negative pressure during high consumption period. The negative pressure indicates that the area supplied by nodes 65, 66 and 72 should not gate water at maximum consumption hours.

The pressure at node-215 is greater than the recommended pressure 60mH2o. High value of pressures affects adversely the hydraulic performance of the distribution network at night time during low consumption period, the pressure in the system become high and it causes pipe burst at the lower location. Also produce low velocities which accelerate the deterioration and corrosion of the pipes in the distribution system.

Table 4. 7 Pressure distributions at peak hour time.

Pressure range	< 15 mH2o	(15-60 mH2o)	>60 mH20
Number of Nodes	24	72	1
Percent	24.74	74.23	0.1

As shown in the table 4.7, from the total nodes 24.74%, nodes have pressure below 15m, 74.23% have permissible pressures between 15m and 60m and 0.1% of the node has above 60m.

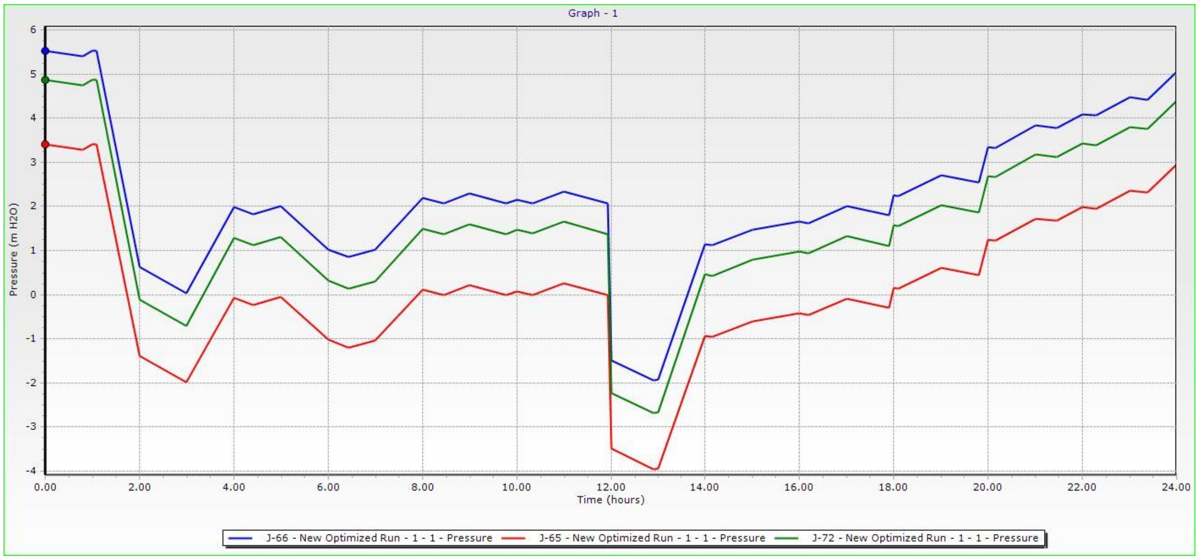


Figure 4. 3 Graph showing nodes with negative pressure.

As shown in figure 4.3, when the system operates at steady state the demand at every node not changing, the pressure for all the three nodes is positive. However, as the demand changes to the peak demand the pressure decreases to negative, therefore, during this time water could not reach to consumers supplied by nodes 65, 66 and 72.

Figure 4. 4 Profiles of nodes showing distance from storage tank-1 (T-1)

Misirdali (2003), showed that as consumption nodes are furthest away from supply points Such as storage reservoirs will always receive less water than those nodes nearest to the source due to pressure losses in the network is increasing as far from the source. The Figure 4.4 shows how distance and elevation affect pressure distribution in selected nodes. In Debre Birhan Town residents living around the market area get water at low pressure and low water pressure creates a low level of reliability of water users on a water supply system. The figure shows the distance from storage tank-1(T-1) to the point of consumption nodes (18, 54, 65, 66, 67, and 72).

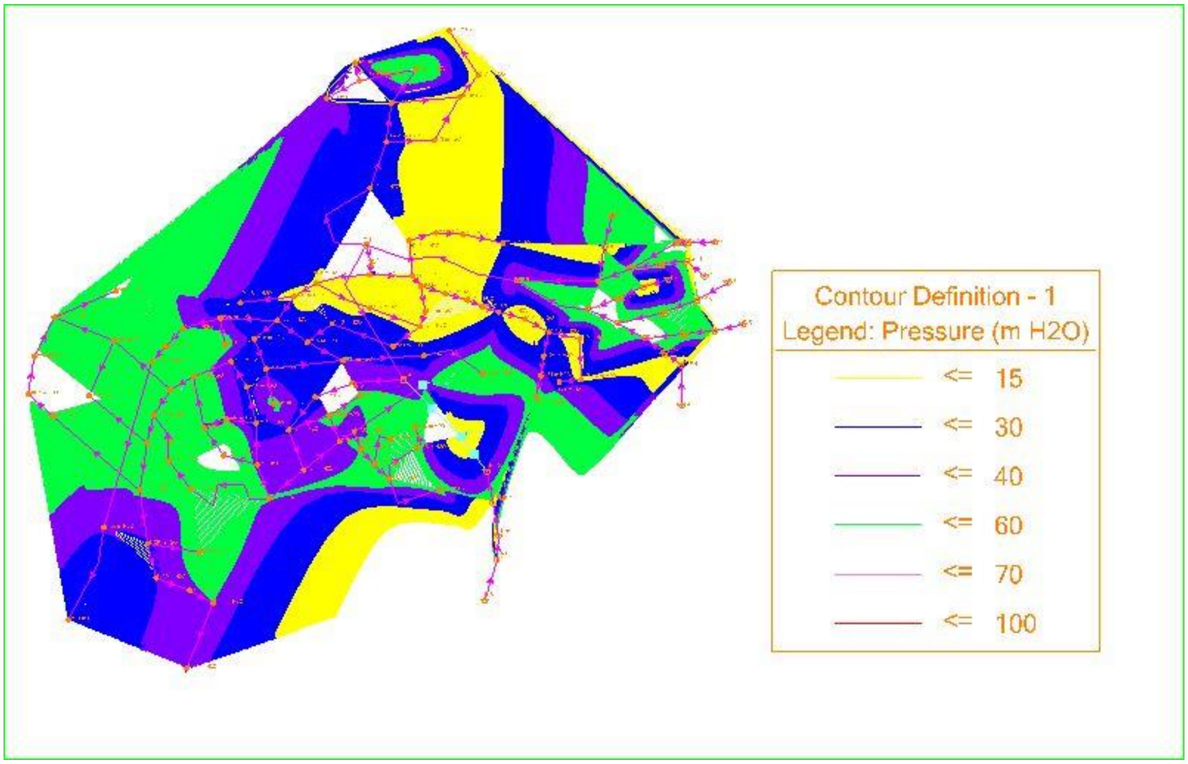


Figure 4. 5 System pressure distributions

The pressures at nodes depend on the topography of the area and the performance of the input energy like pumps. The area highlighted by yellow color in the figure 4.5 is pressure deficit area below 15m water head.

4.7.2 Pipe flow velocity

The allowable velocity in distribution system indicated by the MoWR water supply design criteria recommended pipe flow velocity to be a minimum of 0.6 m/s and maximum of 2m/s.

Table 4. 8 Simulated results of velocity range.

Velocity range (m/s)	Count	Count (%)	Effect
<0.6	110	76.92	Sedimentation problem
0.6-2	26	18.18	Normal
>2	7	4.89	High head loss occurred

As indicated in table 4.8, 76.92% of the pipes are under the permissible range of velocity. Low velocity in pipe flow affects the proper supply of water and undesirable for hygienic reason. When the diameter value of pipe increases the velocity decreases and longtime of retention causes sediment formation.

Figure 4. 6 Main transmission line showing velocity and flow verses time.

The figure shows the velocity and flow increase linearly as the time increases from 2:00 hour up to 24:00 hour.

4.8 Behavior of Storage tank at different consumption hours of a day.

The service reservoir (storage tank) is provided to balance (constant) supply rate from the water source or treatment plant with the fluctuating water demand in distribution area. Dynamic (EPS) simulation result was used to show the fluctuating storage volume with time increments during high and low consumption.

Moreover, in low demand hours when the water consumption of consumer are almost zero, amount of pumped water is higher than system demand so that extra water coming from pumps are stored at storage tank and equilibrium of water distribution system satisfied again. The time varying simulation indicates that storage tank-1 starts to decrease its volume at 2:00 hour that means up to 2: hour the volume in the tank is full.

Figure 4. 7 Tank -1 water volume fluctuation over 24 hour periods.

Figure 4.7 shows during the extended period simulation the storage level of the tank fluctuate for 24 hour period which shows the change in percent of full in different time interval. When the simulation run begins the tank was full and then the volume starts to decrease up to 14 hours, so that the pumps should have to operate to replenish the volume of the tank starting from 14 hours.

4.9 Pump

Pump is one of the important elements, which add energy to the system. Since water can flows from the higher energy location to the lower energy. Pumps used to boost the head at desired locations to overcome desired piping head losses physical elevation difference.

4.9.1 Pump capacity curve

A pump curve represents the relationship between the head and flow rate can deliver water at nominal speed settings. Pump head is the head gain imported to the water by the pump and plotted on the vertical of the curve in meter.

Figure 4. 8 Pump –head verses flow curve

A pump is defined by its characteristic curve, which relates the head added to the system to the flow rates. Figure 4.8, shows as the head increases the amount of discharge pushed by the pump decreases. When the head decreases the pump can push high amount of discharge to a lower elevation so the pump curve indicates decreasing head with increasing flow.

4.10 Calibration of hydraulic network model

Calibration is the process of comparing the model results to field observations, and if necessary, adjusting the model parameters until model results reasonably agree with measured system performances over a range of operational conditions (Maluku, 2015).

Although necessary data have been collected for water distribution modeling and simulated by hydraulic modeling software, the simulated result should not be expected as accurate mathematical representation.

The hydraulic simulation software simply solves continuity and energy equations using the input data. Thus, the quality of the input data, will affect the quality of the model result. The accurate representation of hydraulic model depends on how well the simulated result approach to the observed field data, regarding to this a model should be calibrated before using for decision making (EPA, 2005a).

4.10.1 Sampling location

Hundreds or thousands of links and nodes may require for a typical network representation. Ideally, during the water distributions model calibration process is adjusted for each link and each node. However, only some percentage of representative sample measurement can be made available for the use of model calibration due to shortage of financial and labor requirements for data collection and measuring.

Then representative sample nodes were selected for the model calibration purpose. The measurements were taken near the supply main nodes at home faucet. Ten data sets were selected from field observation and ten data sets were selected from simulated results. It was difficult to take measurement at a direct connection to the water main nodes, due to the availability of pressure gauges.

For the calibration, the head loss between the supply main nodes and the site where pressure is measured has been considered. The head loss includes the elevation head and pipe friction loss.

As a result, 100% of field test measurement was within ± 2m, showing an acceptable level of pressure calibration criteria. The locations between main sample nodes and the corresponding field measurement locations has represented in table 4.9.

Table 4. 9 Location of sample nodes and the corresponding field test

Sample node location				Corresponding field test location			Head loss between two locations		
Label	X	Y	Z	X	Y	Z	Elevation head (m)	Friction loss (m)	Total head loss (m)
J-30	558400	1069338	2835.4	559448	1068848	2835.2	0.2	0.1	0.3
J-28	557957	1069075	2835.5	556897	1068953	2833.28	2.17	0.04	2.21
J-22	557623	1068603	2826	558215	1068179	2825.74	0.26	0.16	0.42
J-17	556502	1068647	2814	556604	1068127	2811.36	2.6	0.01	2.7
J-38	560286	1069475	2840.4	559657	1070528	2839.98	0.42	0.05	0.47
J-37	560449	1069279	2844.5	560535	1068774	2842.36	2.07	0.08	2.15
J-18	559451	1071206	2824.9	559770	1072117	2825.41	0.5	0.49	0.99
J-48	561656	1068874	2843.6	561974	1068774	2841.6	2.04	0.02	2.06
J-40	560657	1070570	2841.7	561301	1070411	2838.08	3.567	0.01	3.58
J-114A	555532	1067245	2769.7	554423	1068207	2767.85	1.86	0.15	2.01

Table 4.10 Comparison of simulated pressure results with corresponding field observation

Sample Node	Simulated model pressure (mH2o)	Filed measured pressure at customer tap(mH2o)	Total head loss between two nodes (m)	The likely simulated pressure at supply main node (m)	Error (m)	Measurement times	Scenario
J-30	15.97	13.75	0.30	14.05	0.3	At high and low consumption hour.	Base scenario
J-28	16.145	17.83	2.21	18.355	0.525		
J-22	20.8	18.8	0.42	20.38	1.58		
J-17	34.775	32.63	2.70	32.075	-0.555		
J-38	17.02	12.825	0.47	17.49	1.5		
J-37	14.32	12.46	2.15	12.17	-0.29		
J-18	23.61	22.83	0.99	24.6	0.01		
J-48	14.32	11.86	2.06	12.26	0.4		
J-40	11.025	9.53	3.58	7.445	-2.085		
J-114A	47.05	45.42	2.01	45.04	-0.38		

The agreement between the observed field data and the model result graphically sketched to show the overall relationship in between the two data sets.

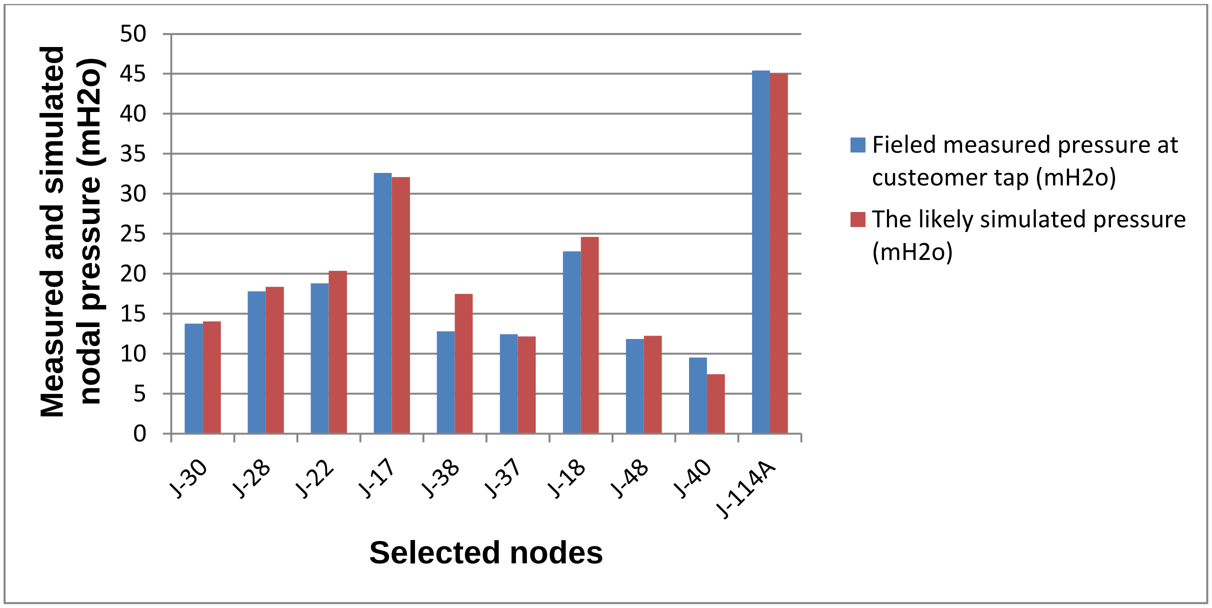


Figure 4. 9 Calibrated model with time series data

Lingreddy (1997), showed that deviation between results of the model application and the field observation may be caused by several factors such as measurement equipment errors and reading wrong value from measurement. In the figure 4.9, at junction (22, 38, and 18), the simulated result and the measured data value have shown devotions in the relationship of the two data sets. The model is over estimated at the stated junctions.

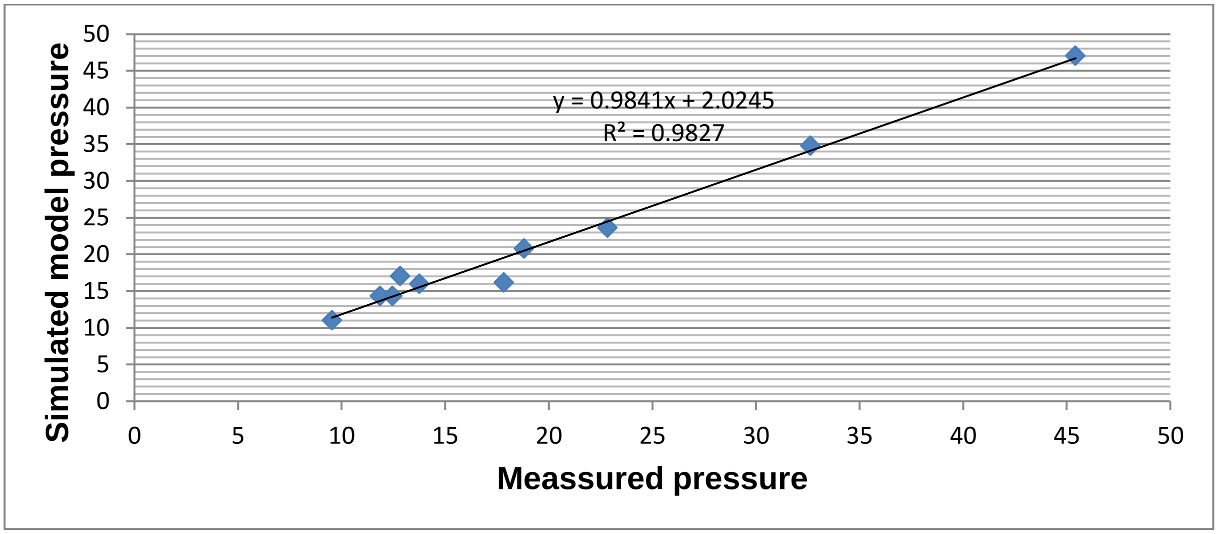


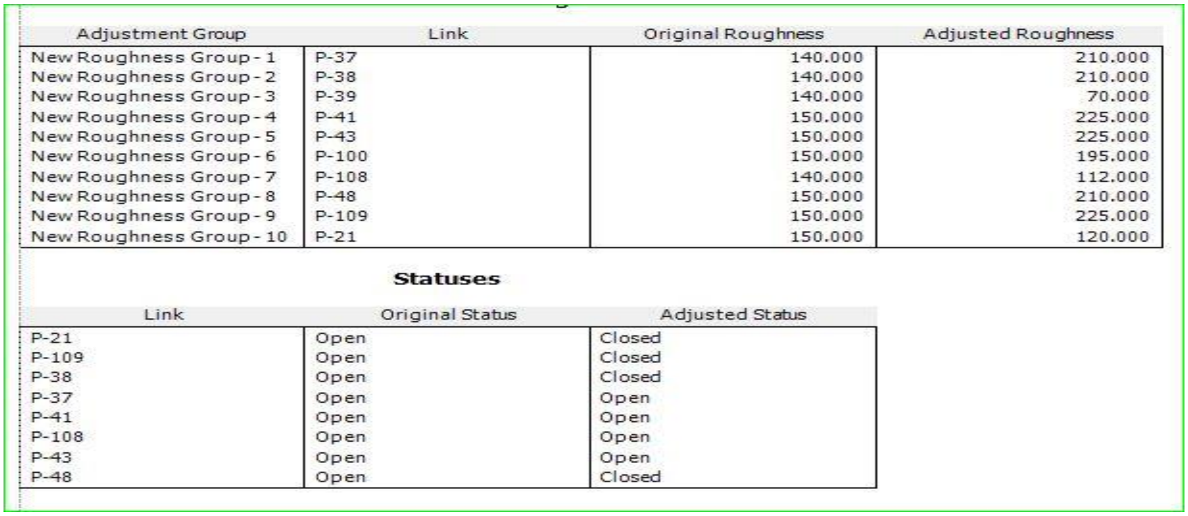
Figure 4. 10 The scatter plotted between measured and simulated pressure for calibration.

In the figure 4.10, the calibration result for coefficient of determination (R^2*)* accounts 98% which shows strong linear relationship between simulated and observed values. The detailed calculation for the coefficient of determination is presented in appendix (5).

4.10.2 Model parameter

One of the primary model parameter associated with a hydraulic network model is pipe roughness. Due to the difficulty of obtaining economic and reliable measurements of the parameters, final model values should be adjusted through the process of model calibration. Model calibration involves the adjustment of primary network model parameters of pipe roughness (Almasri, 2010).

A model is adjusted to better match the actual behavior of water distribution system by using Darwin calibrator. The observed filed data were entered to field data snapshot tap and using fitness of minimize maximum difference and running the Darwin calibration at optimization run, the model was calibrated.



Adjustment Group	Link	Original Roughness	Adjusted Roughness
New Roughness Group - 1	P-37	140.000	210.000
New Roughness Group - 2	P-38	140.000	210.000
New Roughness Group - 3	P-39	140.000	70.000
New Roughness Group - 4	P-41	150.000	225.000
New Roughness Group - 5	P-43	150.000	225.000
New Roughness Group - 6	P-100	150.000	195.000
New Roughness Group - 7	P-108	140.000	112.000
New Roughness Group - 8	P-48	150.000	210.000
New Roughness Group - 9	P-109	150.000	225.000
New Roughness Group - 10	P-21	150.000	120.000

Statuses

Link	Original Status	Adjusted Status
P-21	Open	Closed
P-109	Open	Closed
P-38	Open	Closed
P-37	Open	Open
P-41	Open	Open
P-108	Open	Open
P-43	Open	Open
P-48	Open	Closed

Figure 4. 11 Original and adjusted pipe roughness values

As shown in figure 4.11, the roughness values of the pipes adjusted to new roughness values which is increasing and decreasing from the original value. As the roughness value of a pipe increases the head loss decreases and as it deceases the head loss increases therefore the roughness values for pipe (P-37, 38, 39, 41, 43, 21, 48, 100, 108 and 109) changed from roughness values to a roughness value of (140-210, 140-210, 140-70, 150-225, 150-225, 150-195,140-112, 150-210, 150-225 and 150-120). The new roughness, generated from the Darwin calibration, entered to the software as the roughness values for the stated pipes so that the simulation analysis has valid. Therefore the model response to a new pipe roughness is valid.

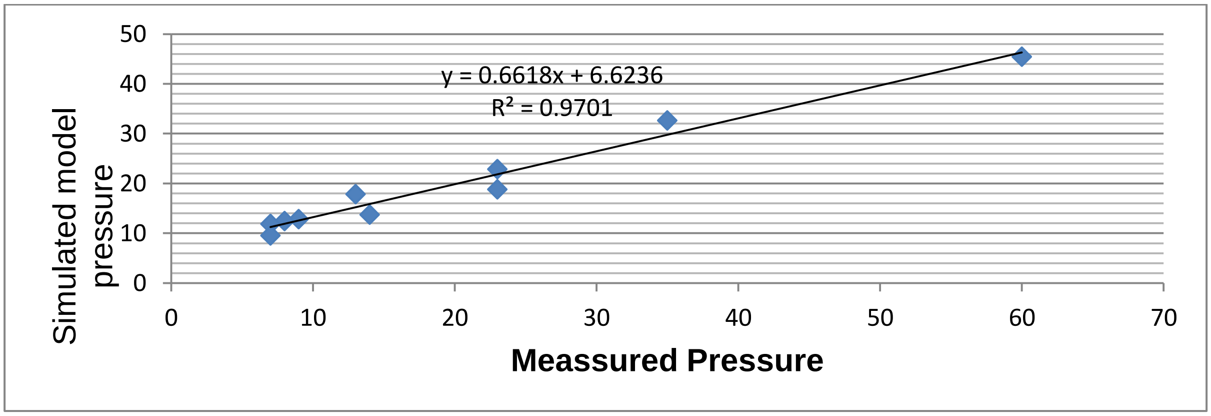


Figure 4. 12 Scatter plots of observed Vs simulated pressure for validation

The coefficient of determination (R^2) accounts 97% of the variance after roughness of the pipe adjusted which shows strong linear relationship at validation phase.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The best performance indicators for water distribution modeling results are: pressure head at network nodes (15-60m head) and flow velocity in pipes (0.6-2m/s) (MoWR, 2006).

In this study the following findings has been extracted and concluded:

- The total average per capita consumption of the town in the year 2015 was 15.62 l/p/d which shows lower performance as compared to 20 l/p/d which is set by WHO (2008) within a radius of 0.5 km.
- The future population and water demand of the town has been projected up to the year 2030 using year 2015 as base year. The projected water demand shows an increment greater than the current water supply potential of existing boreholes. The demand for the year 2030 exceeds by 74.58% as compared to year 2015 production capacity of existing wells.
- The overall behavior of the distribution system within 24 hours of a day was assessed which help to plan management and operation of the distribution systems.
- The performance of the distribution system has shown 25.77% of consumption nodes have out of the indicated range of performance. 74.23% nodes have acceptable pressure limits between (15-60mH2o).
- The simulated result for the distribution system was resulted 24.74% nodes has been found below the acceptable limits of pressure value (<15mH2o), in pressure zone one due to high elevation difference and long distance from the source.
- The result for dynamic simulation for 24 hour period and during high consumption period nodes (65, 66 and 72) have negative pressure. The nodes are furthest from the source of supply point storage tank (T-1). As the distance increases the water pressure diminishes in distribution system. The negative value of pressure indicates that the area supplied by those nodes could not get water in peak demand hours. Therefore, areas which need zoning to enable the system to continuously supply the residents at all demanding time is known.

- The cause of sedimentations has been identified from 76.92% of water distribution pipes with velocity below the acceptable limits (< 0.6m/s). When the flow is moving very slow in pipes the very tinny materials remains on the inner wall of the pipes and causes water quality problems. The locations of pipes with high head loss are known from 4.89% for velocity values (> 2m/s).

5.2 Recommendations

In order to improve in terms of distribution performance and water supply coverage of the town the following activity should be performed:

- As this study, was specifically limited to evaluate hydraulic performance related to pressure and pipe flow velocity and to forecast the future population and demand a study should be undertaken related to spatial allocation of demand and leakage detection of the system.
- Debre Birhan water supply office should have to gather x, y, coordinates of all of the components of water supply distribution network, its customers water meter and prepare population layer by shape file in order to model the distribution system using water CAD with GIS integrated software. When working with high quality GIS data the demand precisely assigned to nodes.
- Since the boreholes are the only source of potable water for the town, around the watershed area of the boreholes, soil and water conservation practice should be conducted to increase the recharge for sustainable uses.
- To increase the reliability of water supply coverage the ground water sources has to be augmented by surface water.
- The simulated result has shown low pressure at a nodes supplied by storage tank one; therefore the water supply office should have to construct additional reservoir or have to increase zoning around the market area of the town.
- Necessary pressure augmenting valves should be installed to upraise pressure during peak demand time. More of the pipes are found under low flow velocity so that, the diameter of the pipes should be minimized to upgrade the quality of water in the system.

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APPENDICES

Appendix AB Link input data for Bentley water CADV8i

Label	Diameter (mm)	Material	Hazen-Williams C	Length (User Defined) (m)
P-1	250.0	Steel	140.0	1,324
P-2	150.0	PVC	150.0	260
P-3	100.0	PVC	150.0	53
P-4	200.0	Steel	140.0	368
P-5	200.0	Steel	140.0	803
P-6	250.0	Steel	140.0	746
P-7	300.0	Steel	140.0	2,148
P-8	80.0	PVC	150.0	152
P-9	150.0	PVC	150.0	275
P-10	150.0	PVC	150.0	42
P-11	100.0	PVC	150.0	113
P-12	80.0	PVC	150.0	243
P-13	90.0	PVC	130.0	482
P-14	90.0	PVC	150.0	561
P-15	90.0	PVC	150.0	232
P-16	150.0	PVC	150.0	1,331
P-17	100.0	PVC	150.0	284
P-18	80.0	PVC	150.0	443
P-19	80.0	PVC	150.0	630
P-20	80.0	PVC	150.0	550
P-21	150.0	PVC	150.0	111
P-22	110.0	PVC	150.0	793
P-23	110.0	PVC	150.0	1,412
P-24	110.0	PVC	150.0	1,377
P-25	150.0	PVC	150.0	220

P-26	150.0	PVC	150.0	397
P-27	110.0	PVC	150.0	185
P-28	110.0	PVC	150.0	116
P-29	110.0	PVC	150.0	220
P-30	110.0	PVC	150.0	92
P-31	150.0	PVC	150.0	330
P-32	110.0	PVC	150.0	363
P-33	150.0	PVC	150.0	1,534
P-34	200.0	Steel	140.0	728
P-35	200.0	Steel	140.0	590
P-37	300.0	Steel	140.0	782
P-38	200.0	Steel	140.0	218
P-39	200.0	Steel	140.0	261
P-40	300.0	Steel	140.0	134
P-41	150.0	PVC	150.0	297
P-42	150.0	PVC	150.0	247
P-43	150.0	PVC	150.0	281
P-44	100.0	PVC	150.0	264
P-45	200.0	PVC	150.0	163
P-46	150.0	PVC	150.0	15
P-47	100.0	PVC	150.0	251
P-48	150.0	PVC	150.0	247
P-49	150.0	PVC	150.0	236
P-50	150.0	PVC	150.0	454
P-51	80.0	PVC	150.0	355
P-52	80.0	PVC	150.0	50
P-53	100.0	PVC	150.0	518
P-54	80.0	PVC	150.0	366
P-55	100.0	PVC	150.0	198
P-56	100.0	PVC	150.0	25
P-57	80.0	PVC	150.0	259

P-58	150.0	PVC	150.0	287
P-59	150.0	PVC	150.0	193
P-60	150.0	PVC	150.0	215
P-61	150.0	PVC	150.0	476
P-62	80.0	PVC	150.0	74
P-63	80.0	PVC	150.0	236
P-64	80.0	PVC	150.0	486
P-65	80.0	PVC	150.0	317
P-66	150.0	Steel	140.0	368
P-67	150.0	PVC	150.0	118
P-68	150.0	PVC	150.0	180
P-69	150.0	PVC	150.0	270
P-70	100.0	PVC	150.0	53
P-71	100.0	PVC	150.0	381
P-72	300.0	Steel	140.0	543
P-73	300.0	Steel	140.0	87
P-74	100.0	PVC	150.0	174
P-75	200.0	Steel	140.0	249
P-76	200.0	Steel	140.0	314
P-77	200.0	Steel	140.0	20
P-78	100.0	PVC	130.0	443
P-79	200.0	Steel	140.0	390
P-80	100.0	PVC	150.0	197
P-81	100.0	PVC	150.0	179
P-82	200.0	Steel	140.0	242
P-83	200.0	Steel	140.0	192
P-84	200.0	Steel	140.0	390
P-85	100.0	PVC	150.0	322
P-86	200.0	Steel	140.0	165
P-87	150.0	PVC	150.0	315
P-88	150.0	PVC	150.0	243

P-89	80.0	PVC	150.0	416
P-90	100.0	PVC	150.0	347
P-91	150.0	PVC	150.0	430
P-92	80.0	PVC	150.0	142
P-93	200.0	Steel	140.0	1,013
P-94	80.0	PVC	150.0	131
P-95	80.0	PVC	130.0	285
P-96	80.0	PVC	150.0	248
P-97	80.0	PVC	150.0	162
P-98	80.0	PVC	150.0	32
P-99	80.0	PVC	150.0	112
P-100	100.0	PVC	150.0	100
P-101	100.0	PVC	150.0	471
P-102	100.0	PVC	150.0	261
P-103	100.0	PVC	150.0	65
P-104	80.0	PVC	150.0	273
P-105	200.0	Steel	140.0	131
P-106	200.0	Steel	140.0	100
P-107	200.0	Steel	140.0	28
P-108	200.0	Steel	140.0	235
P-109	80.0	PVC	150.0	180
P-110	80.0	PVC	150.0	538
P-111	80.0	PVC	150.0	200
P-112	300.0	Steel	140.0	115
P-113	300.0	Steel	140.0	206
P-114	150.0	Steel	140.0	2
P-115	150.0	Steel	140.0	2
P-116	150.0	Steel	140.0	57
P-117	150.0	Steel	140.0	2
P-118	150.0	Steel	140.0	2
P-119	150.0	Steel	140.0	2

P-120	150.0	Steel	140.0	2
P-121	150.0	Steel	140.0	2
P-122	150.0	Steel	140.0	810
P-123	300.0	Steel	140.0	2
P-124	300.0	Steel	140.0	337
P-125	250.0	Steel	140.0	2
P-126	250.0	Steel	140.0	2,014
P-127	150.0	Steel	140.0	2
P-128	350.0	Steel	140.0	26
P-129	350.0	Steel	140.0	214
P-130	350.0	Steel	140.0	92
P-131	350.0	Steel	140.0	238
P-132	150.0	Steel	140.0	223
P-133	150.0	Steel	140.0	746
P-134	150.0	Steel	140.0	16
P-135	150.0	Steel	140.0	56
P-136	150.0	Steel	140.0	46
P-137	150.0	Steel	140.0	298
P-138	150.0	Steel	140.0	16
P-139	150.0	Steel	140.0	57
P-140	150.0	Steel	140.0	55
P-141	150.0	Steel	140.0	279
P-142	150.0	Steel	140.0	243
P-143	150.0	Steel	140.0	353

Appendix AB Node input data for Bentley water CADV8i

Label	Elevation (m)	X (m)	Y (m)
J-102	2,793.86	559,136.91	1,066,419.80
J-102A	2,791.96	560,494.34	1,067,338.58

J-102B	2,794.69	558,849.75	1,066,226.24
J-104	2,796.01	558,144.84	1,065,670.60
J-105	2,800.50	557,851.67	1,066,452.71
J-105A	2,787.40	559,248.03	1,067,132.91
J-105B	2,784.65	558,650.07	1,066,738.60
J-105C	2,811.24	558,373.09	1,067,106.77
J-107	2,792.37	557,236.77	1,065,774.77
J-109	2,805.10	557,216.97	1,066,588.39
J-111	2,790.32	556,184.50	1,066,496.75
J-112	2,803.49	557,027.77	1,067,300.49
J-113	2,799.50	556,720.79	1,067,801.95
J-114	2,778.24	555,982.46	1,067,500.97
J-114A	2,769.71	555,532.15	1,067,245.10
J-120	2,788.87	556,370.57	1,063,058.29
J-121	2,791.08	555,904.39	1,063,300.19
J-122	2,799.22	555,246.91	1,063,548.63
J-123	2,800.36	555,080.62	1,064,221.07
J-124	2,783.05	556,101.56	1,064,054.02
J-127	2,774.09	555,197.69	1,066,747.77
J-127A	2,778.18	555,069.87	1,066,196.96
J-133	2,769.67	553,210.12	1,066,728.41
J-159A	2,801.42	562,708.83	1,067,103.00
J-16	2,803.00	556,604.57	1,068,127.13
J-163	2,788.30	561,662.54	1,067,547.70
J-167A	2,771.95	559,271.99	1,066,069.37
J-167B	2,776.00	559,530.17	1,065,779.13
J-167C	2,778.74	559,830.14	1,065,489.21
J-167D	2,779.98	560,355.93	1,066,098.18
J-167E	2,778.39	559,847.71	1,066,271.31
J-167F	2,780.15	560,805.78	1,065,277.24
J-167G	2,779.77	560,332.93	1,066,504.12

J-17	2,813.96	556,502.63	1,068,647.67
J-18	2,824.91	559,451.47	1,071,206.90
J-208	2,768.24	553,930.30	1,067,129.49
J-208A	2,780.59	554,423.34	1,068,207.48
J-21	2,830.95	556,897.17	1,068,953.54
J-210	2,767.30	552,853.51	1,067,895.13
J-210A	2,777.88	553,252.92	1,068,667.68
J-210B	2,767.10	554,462.11	1,069,188.95
J-211	2,783.40	555,934.30	1,065,297.51
J-212	2,779.26	555,493.19	1,065,845.81
J-214	2,767.23	552,733.01	1,067,162.98
J-215	2,759.66	556,575.36	1,065,953.13
J-216	2,793.29	555,851.89	1,061,781.47
J-217	2,788.18	557,475.22	1,065,108.81
J-22	2,826.00	557,623.00	1,068,603.46
J-221	2,790.06	556,626.31	1,066,664.06
J-225	2,787.63	554,924.79	1,065,267.42
J-23	2,823.00	557,173.87	1,068,241.89
J-24	2,822.25	557,403.40	1,067,652.55
J-25	2,803.90	557,551.19	1,066,961.77
J-26	2,817.46	558,912.66	1,067,817.49
J-27	2,829.96	558,215.92	1,068,179.86
J-28	2,835.45	557,957.66	1,069,075.48
J-3	2,827.57	553,523.10	1,062,728.34
J-30	2,835.40	558,400.47	1,069,338.62
J-30A	2,840.00	559,445.39	1,069,501.72
J-31	2,835.20	559,448.47	1,068,848.83
J-33	2,825.75	560,507.42	1,067,915.59
J-34	2,832.56	558,701.20	1,068,543.13
J-35	2,825.84	559,895.01	1,068,096.94
J-36	2,842.70	560,427.84	1,068,483.91

J-36A	2,842.36	560,535.53	1,068,774.61
J-37	2,844.53	560,449.41	1,069,279.46
J-38	2,840.40	560,286.70	1,069,475.64
J-39	2,839.98	560,217.96	1,070,177.21
J-4	2,818.28	554,219.99	1,064,539.64
J-40	2,841.65	560,744.32	1,070,330.22
J-41	2,844.00	560,925.41	1,069,136.25
J-46	2,844.16	561,358.52	1,069,004.99
J-47	2,838.08	561,273.89	1,070,297.42
J-48	2,843.64	561,656.03	1,068,874.20
J-5	2,807.86	555,773.06	1,068,455.14
J-51	2,830.30	561,974.69	1,068,774.01
J-52	2,850.00	562,499.22	1,068,633.20
J-52A	2,836.32	563,599.58	1,067,443.92
J-53	2,833.00	562,063.14	1,070,126.20
J-54	2,825.41	559,770.14	1,072,117.34
J-54A	2,830.97	559,870.28	1,072,875.37
J-54B	2,700.43	560,352.77	1,073,533.79
J-54C	2,880.59	559,233.52	1,073,315.41
J-54D	2,668.53	557,526.73	1,073,164.93
J-54E	2,658.35	559,124.50	1,074,429.95
J-57	2,831.19	562,964.68	1,068,373.08
J-58B	2,839.65	563,569.06	1,068,244.09
J-59	2,814.45	562,803.79	1,067,519.31
J-6	2,802.40	555,162.16	1,067,793.80
J-60	2,824.80	562,851.29	1,067,897.14
J-60B	2,824.60	563,167.24	1,067,393.68
J-65	2,844.88	560,709.46	1,072,139.59
J-66	2,842.75	561,208.39	1,072,992.22
J-67	2,840.87	561,573.53	1,073,418.30
J-7	2,803.51	555,438.76	1,068,087.36

J-72	2,843.40	561,009.65	1,074,297.35
J-1	2,798.50	563,938.38	1,069,380.58

Appendix-1 –Steady state simulation (1.1- Nodes at average day demand)

Label	Elevation (m)	Demand (L/s)	Pressure (m H2O)	Pressure Head (m)
J-102	2,793.86	20	31	31.08
J-102A	2,791.96	0	33	32.98
J-102B	2,794.69	0	34	33.87
J-104	2,796.01	1	33	33.43
J-105	2,800.50	0	29	29.11
J-105A	2,787.40	0	41	41.57
J-105B	2,784.65	0	44	44.32
J-105C	2,811.24	1	18	18.53
J-107	2,792.37	0	37	36.86
J-109	2,805.10	1	24	23.90
J-111	2,790.32	1	38	38.47
J-112	2,803.49	0	25	25.39
J-113	2,799.50	1	29	29.29
J-114	2,778.24	1	50	50.28
J-114A	2,769.71	0	59	58.64
J-120	2,788.87	0	38	37.97
J-121	2,791.08	0	36	35.80
J-122	2,799.22	1	28	27.78
J-123	2,800.36	1	27	27.45
J-124	2,783.05	0	45	44.72
J-127	2,774.09	1	54	54.22
J-127A	2,778.18	1	50	50.06
J-133	2,769.67	1	58	58.06

J-159A	2,801.42	0	47	47.27
J-16	2,803.00	0	45	45.54
J-163	2,788.30	0	60	59.78
J-167A	2,771.95	0	52	52.55
J-167B	2,776.00	0	48	48.41
J-167C	2,778.74	1	46	45.63
J-167D	2,779.98	1	44	44.38
J-167E	2,778.39	0	46	46.02
J-167F	2,780.15	0	44	44.22
J-167G	2,779.77	0	44	44.59
J-17	2,813.96	1	35	34.59
J-18	2,824.91	2	22	22.19
J-208	2,768.24	1	60	59.92
J-208A	2,780.59	1	48	47.70
J-21	2,830.95	0	18	17.83
J-210	2,767.30	2	60	60.31
J-210A	2,777.88	3	49	49.54
J-210B	2,767.10	1	60	60.08
J-211	2,783.40	1	46	45.71
J-212	2,779.26	1	50	49.78
J-214	2,767.23	1	60	60.45
J-215	2,759.66	1	69	69.43
J-216	2,793.29	0	33	33.54
J-217	2,788.18	1	41	41.07
J-22	2,826.00	1	23	22.70
J-221	2,790.06	0	39	38.75
J-225	2,787.63	1	40	40.23
J-23	2,823.00	0	26	25.58
J-24	2,822.25	0	26	26.32
J-25	2,803.90	0	45	44.66
J-26	2,817.46	1	31	31.06

J-27	2,829.96	1	19	18.67
J-28	2,835.45	1	13	13.35
J-3	2,827.57	0	21	20.62
J-30	2,835.40	1	13	13.50
J-30A	2,840.00	1	9	8.97
J-31	2,835.20	0	14	13.66
J-33	2,825.75	1	22	22.35
J-34	2,832.56	0	16	16.16
J-35	2,825.84	0	23	22.89
J-36	2,842.70	0	6	6.14
J-36A	2,842.36	0	7	6.56
J-37	2,844.53	0	4	4.42
J-38	2,840.40	1	9	8.57
J-39	2,839.98	0	9	8.97
J-4	2,818.28	1	30	29.92
J-40	2,841.65	0	7	7.29
J-41	2,844.00	0	5	4.94
J-46	2,844.16	0	5	4.78
J-47	2,838.08	0	11	10.85
J-48	2,843.64	0	5	5.29
J-5	2,807.86	0	41	40.61
J-51	2,830.30	0	19	18.62
J-52	2,826.20	0	23	22.72
J-52A	2,836.32	0	12	12.42
J-53	2,833.00	0	16	15.93
J-54	2,825.41	1	21	21.49
J-54A	2,830.97	1	16	15.83
J-54B	2,785.00	1	62	61.73
J-54C	2,838.60	1	8	7.52
J-54D	2,813.65	0	32	32.46
J-54E	2,815.69	0	30	30.38

J-57	2,831.19	1	18	17.55
J-58B	2,839.65	0	9	9.09
J-59	2,814.45	0	34	34.25
J-6	2,802.40	2	46	45.89
J-60	2,824.80	0	24	23.91
J-60B	2,824.60	0	24	24.14
J-65	2,844.88	1	2	1.87
J-66	2,842.75	1	4	3.95
J-67	2,840.87	0	6	5.82
J-7	2,803.51	1	45	44.89
J-72	2,843.40	0	3	3.26
J-1	2,798.50	0	59	59.33

Debre Birhan water supply model.wtg
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Bentley WaterCAD V8i (SELECTseries 6)
[08.11.06.58]
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Appendix-1 Steady state simulation (1.1 Links at average day demand)

Label	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	head loss Gradient (m/km)
P-1	250.0	Steel	140.0	26	0.54	1.160
P-2	150.0	PVC	150.0	11	0.63	2.476
P-3	100.0	PVC	150.0	0	0.01	0.000
P-4	200.0	Steel	140.0	3	0.11	0.080
P-5	200.0	Steel	140.0	24	0.77	2.881
P-6	250.0	Steel	140.0	45	0.92	3.132
P-7	300.0	Steel	140.0	72	1.01	3.024
P-8	80.0	PVC	150.0	1	0.17	0.435
0P-9	150.0	PVC	150.0	0	0.03	0.008
P-10	150.0	PVC	150.0	0	0.01	0.000
P-11	100.0	PVC	150.0	0	0.01	0.003
P-12	80.0	PVC	150.0	1	0.11	0.197
P-13	90.0	PVC	130.0	2	0.28	1.270
P-14	90.0	PVC	150.0	0	0.07	0.087
P-15	90.0	PVC	150.0	0	0.03	0.017
P-16	150.0	PVC	150.0	2	0.09	0.069
P-17	100.0	PVC	150.0	0	0.03	0.015
P-18	80.0	PVC	150.0	-1	0.20	0.613
P-19	80.0	PVC	150.0	0	0.08	0.118
P-20	80.0	PVC	150.0	-1	0.12	0.229
P-21	150.0	PVC	150.0	-5	0.28	0.560
P-22	110.0	PVC	150.0	3	0.33	1.099
P-23	110.0	PVC	150.0	-1	0.11	0.138
P-24	110.0	PVC	150.0	1	0.12	0.173
P-25	150.0	PVC	150.0	3	0.18	0.231
P-26	150.0	PVC	150.0	3	0.15	0.164
P-27	110.0	PVC	150.0	2	0.22	0.494

P-28	110.0	PVC	150.0	2	0.17	0.326
P-29	110.0	PVC	150.0	0	0.02	0.005
P-30	110.0	PVC	150.0	0	0.01	0.000
P-31	150.0	PVC	150.0	1	0.05	0.023
P-32	110.0	PVC	150.0	0	0.03	0.015
P-33	150.0	PVC	150.0	8	0.43	1.239
P-34	200.0	Steel	140.0	6	0.18	0.190
P-35	200.0	Steel	140.0	4	0.14	0.125
P-37	300.0	Steel	140.0	11	0.15	0.090
P-38	200.0	Steel	140.0	9	0.29	0.475
P-39	200.0	Steel	140.0	8	0.26	0.388
P-40	300.0	Steel	140.0	7	0.09	0.036
P-41	150.0	PVC	150.0	2	0.09	0.068
P-42	150.0	PVC	150.0	1	0.06	0.036
P-43	150.0	PVC	150.0	1	0.04	0.015
P-44	100.0	PVC	150.0	0	0.03	0.012
P-45	200.0	PVC	150.0	5	0.14	0.117
P-46	150.0	PVC	150.0	2	0.12	0.119
P-47	100.0	PVC	150.0	2	0.25	0.716
P-48	150.0	PVC	150.0	-6	0.35	0.824
P-49	150.0	PVC	150.0	-4	0.23	0.391
P-50	150.0	PVC	150.0	3	0.14	0.162
P-51	80.0	PVC	150.0	1	0.13	0.290
P-52	80.0	PVC	150.0	1	0.13	0.286
P-53	100.0	PVC	150.0	1	0.15	0.284
P-54	80.0	PVC	150.0	0	0.06	0.070
P-55	100.0	PVC	150.0	2	0.22	0.577
P-56	100.0	PVC	150.0	2	0.20	0.464
P-57	80.0	PVC	150.0	0	0.04	0.038
P-58	150.0	PVC	150.0	5	0.27	0.520
P-59	150.0	PVC	150.0	4	0.23	0.387

P-60	150.0	PVC	150.0	4	0.21	0.327
P-61	150.0	PVC	150.0	3	0.18	0.238
P-62	80.0	PVC	150.0	1	0.21	0.652
P-63	80.0	PVC	150.0	-1	0.17	0.458
P-64	80.0	PVC	150.0	1	0.24	0.871
P-65	80.0	PVC	150.0	0	0.05	0.054
P-66	150.0	Steel	140.0	2	0.09	0.080
P-67	150.0	PVC	150.0	0	0.01	0.000
P-68	150.0	PVC	150.0	11	0.60	2.244
P-69	150.0	PVC	150.0	-13	0.73	3.235
P-70	100.0	PVC	150.0	23	2.93	68.371
P-71	100.0	PVC	150.0	3	0.32	1.157
P-72	300.0	Steel	140.0	22	0.32	0.348
P-73	300.0	Steel	140.0	16	0.22	0.181
P-74	100.0	PVC	150.0	2	0.27	0.847
P-75	200.0	Steel	140.0	13	0.41	0.928
P-76	200.0	Steel	140.0	11	0.34	0.625
P-77	200.0	Steel	140.0	10	0.33	0.595
P-78	100.0	PVC	130.0	2	0.21	0.658
P-79	200.0	Steel	140.0	11	0.35	0.695
P-80	100.0	PVC	150.0	2	0.20	0.461
P-81	100.0	PVC	150.0	2	0.24	0.652
P-82	200.0	Steel	140.0	11	0.36	0.706
P-83	200.0	Steel	140.0	6	0.18	0.205
P-84	200.0	Steel	140.0	9	0.30	0.503
P-85	100.0	PVC	150.0	-4	0.46	2.248
P-86	200.0	Steel	140.0	9	0.28	0.453
P-87	150.0	PVC	150.0	7	0.42	1.186
P-88	150.0	PVC	150.0	3	0.17	0.218
P-89	80.0	PVC	150.0	0	0.07	0.089
P-90	100.0	PVC	150.0	0	0.04	0.021

P-91	150.0	PVC	150.0	4	0.21	0.314
P-92	80.0	PVC	150.0	1	0.14	0.323
P-93	200.0	Steel	140.0	-66	2.10	18.756
P-94	80.0	PVC	150.0	1	0.14	0.316
P-95	80.0	PVC	130.0	-1	0.12	0.302
P-96	80.0	PVC	150.0	0	0.08	0.100
P-97	80.0	PVC	150.0	1	0.20	0.641
P-98	80.0	PVC	150.0	1	0.17	0.465
P-99	80.0	PVC	150.0	1	0.22	0.718
P-100	100.0	PVC	150.0	1	0.16	0.321
P-101	100.0	PVC	150.0	0	0.05	0.038
P-102	100.0	PVC	150.0	1	0.10	0.135
P-103	100.0	PVC	150.0	1	0.07	0.060
P-104	80.0	PVC	150.0	0	0.05	0.040
P-105	200.0	Steel	140.0	3	0.09	0.057
P-106	200.0	Steel	140.0	3	0.09	0.054
P-107	200.0	Steel	140.0	3	0.08	0.043
P-108	200.0	Steel	140.0	2	0.08	0.041
P-109	80.0	PVC	150.0	0	0.03	0.020
P-110	80.0	PVC	150.0	2	0.32	1.502
P-111	80.0	PVC	150.0	1	0.20	0.610
P-112	300.0	Steel	140.0	48	0.67	1.418
P-113	300.0	Steel	140.0	36	0.51	0.847
P-114	150.0	Steel	140.0	11	0.61	2.679
P-115	150.0	Steel	140.0	21	1.20	9.227
P-116	150.0	Steel	140.0	21	1.20	9.259
P-117	150.0	Steel	140.0	2	0.14	0.149
P-118	150.0	Steel	140.0	3	0.15	0.149
P-119	150.0	Steel	140.0	4	0.24	0.446
P-120	150.0	Steel	140.0	17	0.97	6.251
P-121	150.0	Steel	140.0	91	5.17	138.708

P-122	150.0	Steel	140.0	91	5.17	138.673
P-123	300.0	Steel	140.0	556	7.87	134.392
P-124	300.0	Steel	140.0	556	7.87	134.411
P-125	250.0	Steel	140.0	129	2.63	21.878
P-126	250.0	Steel	140.0	129	2.63	21.880
P-127	150.0	Steel	140.0	13	0.75	3.870
P-128	350.0	Steel	140.0	-19	0.19	0.114
P-129	350.0	Steel	140.0	19	0.19	0.117
P-130	350.0	Steel	140.0	48	0.50	0.683
P-131	350.0	Steel	140.0	48	0.50	0.684
P-132	150.0	Steel	140.0	2	0.14	0.176
P-133	150.0	Steel	140.0	3	0.14	0.177
P-134	150.0	Steel	140.0	13	0.75	3.851
P-135	150.0	Steel	140.0	13	0.75	3.854
P-136	150.0	Steel	140.0	11	0.61	2.679
P-137	150.0	Steel	140.0	11	0.61	2.677
P-138	150.0	Steel	140.0	3	0.15	0.186
P-139	150.0	Steel	140.0	3	0.15	0.188
P-140	150.0	Steel	140.0	4	0.24	0.476
P-141	150.0	Steel	140.0	4	0.24	0.476
P-142	150.0	Steel	140.0	17	0.97	6.216
P-143	150.0	Steel	140.0	17	0.97	6.217

	Bentley Systems, Inc. Haestad Methods Solution Center	Bentley WaterCAD V8i (SELECTseries 6)
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10/25/2016	Suite 200 W Watertown, CT 06795 USA +1-203-755-1666	Page 1 of 1

Appendix-2- Extended period simulation (2.1 Nodes at maximum consumption hour)

Label	Elevation (m)	Demand (L/s)	Pressure (m H2O)	Pressure Head (m)
J-102	2,793.86	33	26	25.96
J-102A	2,791.96	0	28	27.86
J-102B	2,794.69	1	34	33.78
J-104	2,796.01	1	34	34.54
J-105	2,800.50	1	30	30.47
J-105A	2,787.40	0	42	42.03
J-105B	2,784.65	1	45	44.78
J-105C	2,811.24	1	20	20.12
J-107	2,792.37	1	38	37.70
J-109	2,805.10	1	24	24.42
J-111	2,790.32	1	39	38.70
J-112	2,803.49	1	26	25.75
J-113	2,799.50	1	29	29.52
J-114	2,778.24	1	50	50.13
J-114A	2,769.71	1	58	58.25
J-120	2,788.87	1	35	35.47
J-121	2,791.08	0	33	33.37
J-122	2,799.22	1	25	25.52
J-123	2,800.36	2	26	26.31
J-124	2,783.05	1	43	43.53
J-127	2,774.09	1	54	53.78
J-127A	2,778.18	2	49	49.51
J-133	2,769.67	1	57	56.81
J-159A	2,801.42	0	45	45.10
J-16	2,803.00	0	43	43.17
J-163	2,788.30	1	57	56.76
J-167A	2,771.95	1	47	46.81
J-167B	2,776.00	1	42	42.55

J-167C	2,778.74	1	40	39.71
J-167D	2,779.98	1	38	38.46
J-167E	2,778.39	0	40	40.16
J-167F	2,780.15	0	38	38.30
J-167G	2,779.77	0	39	38.65
J-17	2,813.96	1	32	32.22
J-18	2,824.91	2	18	17.81
J-208	2,768.24	2	59	59.27
J-208A	2,780.59	2	47	47.22
J-21	2,830.95	0	16	15.78
J-210	2,767.30	2	59	58.90
J-210A	2,777.88	5	48	47.85
J-210B	2,767.10	2	58	58.07
J-211	2,783.40	2	46	46.37
J-212	2,779.26	1	50	50.34
J-214	2,767.23	1	59	59.13
J-215	2,759.66	1	70	70.05
J-216	2,793.29	0	31	31.03
J-217	2,788.18	2	42	41.92
J-22	2,826.00	1	20	20.53
J-221	2,790.06	0	39	38.99
J-225	2,787.63	1	39	39.17
J-23	2,823.00	0	23	23.26
J-24	2,822.25	0	24	23.98
J-25	2,803.90	0	42	42.31
J-26	2,817.46	1	29	28.66
J-27	2,829.96	1	16	16.41
J-28	2,835.45	1	11	11.32
J-3	2,827.57	0	18	17.76
J-30	2,835.40	2	12	11.62
J-30A	2,840.00	2	7	7.19

J-31	2,835.20	1	12	11.72
J-33	2,825.75	1	19	19.36
J-34	2,832.56	0	14	14.02
J-35	2,825.84	0	21	20.78
J-36	2,842.70	1	4	4.16
J-36A	2,842.36	0	5	4.70
J-37	2,844.53	1	3	2.60
J-38	2,840.40	1	7	6.78
J-39	2,839.98	1	7	7.15
J-4	2,818.28	2	27	27.06
J-40	2,841.65	1	5	5.46
J-41	2,844.00	0	3	3.11
J-46	2,844.16	0	3	2.94
J-47	2,838.08	1	9	9.02
J-48	2,843.64	0	3	3.46
J-5	2,807.86	1	38	38.14
J-51	2,830.30	0	17	16.78
J-52	2,826.20	0	21	20.87
J-52A	2,836.32	0	10	10.32
J-53	2,833.00	0	14	14.09
J-54	2,825.41	1	17	16.82
J-54A	2,830.97	1	11	11.04
J-54B	2,785.00	1	57	56.84
J-54C	2,838.60	2	2	1.77
J-54D	2,813.65	0	27	26.71
J-54E	2,815.69	1	25	24.57
J-57	2,831.19	1	15	15.45
J-58B	2,839.65	0	7	6.99
J-59	2,814.45	0	32	32.10
J-6	2,802.40	2	43	43.16
J-60	2,824.80	0	22	21.76

J-60B	2,824.60	0	22	22.04
J-65	2,844.88	1	-3	-3.00
J-66	2,842.75	1	-1	-0.99
J-67	2,840.87	1	1	0.86
J-7	2,803.51	1	42	42.32
J-72	2,843.40	0	-2	-1.73
J-1	2,798.50	0	58	58.02

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Bentley WaterCAD
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Appendix-2 Extended period simulation (2.2 Links at maximum consumption hour)

Label	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Head loss Gradient (m/km)
P-1	250.0	Steel	140.0	27	0.55	1.207
P-2	150.0	PVC	150.0	18	1.01	5.913
P-3	100.0	PVC	150.0	0	0.01	0.000
P-4	200.0	Steel	140.0	4	0.11	0.083
P-5	200.0	Steel	140.0	25	0.79	3.070
P-6	250.0	Steel	140.0	47	0.95	3.298
P-7	300.0	Steel	140.0	74	1.04	3.169
P-8	80.0	PVC	150.0	1	0.27	1.040
P-9	150.0	PVC	150.0	1	0.04	0.018
P-10	150.0	PVC	150.0	0	0.02	0.007

P-11	100.0	PVC	150.0	0	0.02	0.005
P-12	80.0	PVC	150.0	1	0.17	0.473
P-13	90.0	PVC	130.0	3	0.44	3.034
P-14	90.0	PVC	150.0	1	0.12	0.208
P-15	90.0	PVC	150.0	0	0.05	0.041
P-16	150.0	PVC	150.0	3	0.15	0.165
P-17	100.0	PVC	150.0	0	0.05	0.035
P-18	80.0	PVC	150.0	-2	0.32	1.464
P-19	80.0	PVC	150.0	1	0.13	0.282
P-20	80.0	PVC	150.0	-1	0.19	0.548
P-21	150.0	PVC	150.0	-8	0.45	1.341
P-22	110.0	PVC	150.0	5	0.53	2.623
P-23	110.0	PVC	150.0	-2	0.17	0.329
P-24	110.0	PVC	150.0	2	0.20	0.412
P-25	150.0	PVC	150.0	5	0.28	0.553
P-26	150.0	PVC	150.0	4	0.23	0.392
P-27	110.0	PVC	150.0	3	0.35	1.178
P-28	110.0	PVC	150.0	3	0.28	0.780
P-29	110.0	PVC	150.0	0	0.03	0.014
P-30	110.0	PVC	150.0	0	0.01	0.003
P-31	150.0	PVC	150.0	1	0.08	0.056
P-32	110.0	PVC	150.0	0	0.05	0.034
P-33	150.0	PVC	150.0	12	0.69	2.959
P-34	200.0	Steel	140.0	9	0.28	0.453
P-35	200.0	Steel	140.0	7	0.22	0.298
P-37	300.0	Steel	140.0	17	0.24	0.215
P-38	200.0	Steel	140.0	15	0.46	1.135
P-39	200.0	Steel	140.0	13	0.41	0.925
P-40	300.0	Steel	140.0	11	0.15	0.089
P-41	150.0	PVC	150.0	3	0.14	0.162
P-42	150.0	PVC	150.0	2	0.10	0.086

P-43	150.0	PVC	150.0	1	0.06	0.034
P-44	100.0	PVC	150.0	0	0.05	0.032
P-45	200.0	PVC	150.0	7	0.23	0.276
P-46	150.0	PVC	150.0	3	0.20	0.298
P-47	100.0	PVC	150.0	3	0.40	1.709
P-48	150.0	PVC	150.0	-10	0.56	1.969
P-49	150.0	PVC	150.0	-7	0.37	0.932
P-50	150.0	PVC	150.0	4	0.23	0.386
P-51	80.0	PVC	150.0	1	0.21	0.693
P-52	80.0	PVC	150.0	1	0.21	0.685
P-53	100.0	PVC	150.0	2	0.24	0.678
P-54	80.0	PVC	150.0	0	0.10	0.167
P-55	100.0	PVC	150.0	3	0.36	1.380
P-56	100.0	PVC	150.0	2	0.32	1.107
P-57	80.0	PVC	150.0	0	0.07	0.088
P-58	150.0	PVC	150.0	8	0.43	1.241
P-59	150.0	PVC	150.0	7	0.37	0.922
P-60	150.0	PVC	150.0	6	0.34	0.781
P-61	150.0	PVC	150.0	5	0.29	0.570
P-62	80.0	PVC	150.0	2	0.33	1.549
P-63	80.0	PVC	150.0	-1	0.27	1.091
P-64	80.0	PVC	150.0	2	0.39	2.081
P-65	80.0	PVC	150.0	0	0.09	0.128
P-66	150.0	Steel	140.0	2	0.09	0.083
P-67	150.0	PVC	150.0	0	0.01	0.000
P-68	150.0	PVC	150.0	17	0.96	5.359
P-69	150.0	PVC	150.0	-21	1.16	7.725
P-70	100.0	PVC	150.0	37	4.69	163.267
P-71	100.0	PVC	150.0	4	0.52	2.763
P-72	300.0	Steel	140.0	36	0.50	0.830
P-73	300.0	Steel	140.0	25	0.35	0.431

P-74	100.0	PVC	150.0	3	0.44	2.024
P-75	200.0	Steel	140.0	21	0.66	2.213
P-76	200.0	Steel	140.0	17	0.54	1.494
P-77	200.0	Steel	140.0	16	0.52	1.414
P-78	100.0	PVC	130.0	3	0.33	1.572
P-79	200.0	Steel	140.0	18	0.57	1.659
P-80	100.0	PVC	150.0	2	0.32	1.100
P-81	100.0	PVC	150.0	3	0.38	1.560
P-82	200.0	Steel	140.0	18	0.57	1.684
P-83	200.0	Steel	140.0	9	0.29	0.490
P-84	200.0	Steel	140.0	10	0.30	0.524
P-85	100.0	PVC	150.0	-6	0.74	5.369
P-86	200.0	Steel	140.0	14	0.45	1.081
P-87	150.0	PVC	150.0	12	0.68	2.833
P-88	150.0	PVC	150.0	5	0.27	0.521
P-89	80.0	PVC	150.0	1	0.11	0.212
P-90	100.0	PVC	150.0	0	0.06	0.051
P-91	150.0	PVC	150.0	6	0.33	0.748
P-92	80.0	PVC	150.0	1	0.23	0.771
P-93	200.0	Steel	140.0	-59	1.88	15.160
P-94	80.0	PVC	150.0	1	0.22	0.750
P-95	80.0	PVC	130.0	-1	0.19	0.722
P-96	80.0	PVC	150.0	1	0.12	0.240
P-97	80.0	PVC	150.0	2	0.33	1.531
P-98	80.0	PVC	150.0	1	0.27	1.107
P-99	80.0	PVC	150.0	2	0.35	1.717
P-100	100.0	PVC	150.0	2	0.26	0.768
P-101	100.0	PVC	150.0	1	0.08	0.090
P-102	100.0	PVC	150.0	1	0.16	0.322
P-103	100.0	PVC	150.0	1	0.11	0.147
P-104	80.0	PVC	150.0	0	0.07	0.097

P-105	200.0	Steel	140.0	5	0.15	0.139
P-106	200.0	Steel	140.0	4	0.14	0.122
P-107	200.0	Steel	140.0	4	0.13	0.117
P-108	200.0	Steel	140.0	4	0.12	0.096
P-109	80.0	PVC	150.0	0	0.05	0.046
P-110	80.0	PVC	150.0	3	0.52	3.587
P-111	80.0	PVC	150.0	2	0.32	1.457
P-112	300.0	Steel	140.0	76	1.08	3.391
P-113	300.0	Steel	140.0	58	0.82	2.021
P-114	150.0	Steel	140.0	11	0.63	2.828
P-115	150.0	Steel	140.0	22	1.22	9.674
P-116	150.0	Steel	140.0	22	1.22	9.614
P-117	150.0	Steel	140.0	3	0.15	0.149
P-118	150.0	Steel	140.0	3	0.15	0.149
P-119	150.0	Steel	140.0	4	0.25	0.446
P-120	150.0	Steel	140.0	17	0.99	6.400
P-121	150.0	Steel	140.0	91	5.17	138.708
P-122	150.0	Steel	140.0	91	5.17	138.673
P-123	300.0	Steel	140.0	556	7.87	134.392
P-124	300.0	Steel	140.0	556	7.87	134.411
P-125	250.0	Steel	140.0	127	2.59	21.282
P-126	250.0	Steel	140.0	127	2.59	21.209
P-127	150.0	Steel	140.0	14	0.78	4.167
P-128	350.0	Steel	140.0	-30	0.31	0.275
P-129	350.0	Steel	140.0	30	0.31	0.278
P-130	350.0	Steel	140.0	77	0.80	1.631
P-131	350.0	Steel	140.0	77	0.80	1.632
P-132	150.0	Steel	140.0	3	0.15	0.186
P-133	150.0	Steel	140.0	3	0.15	0.186
P-134	150.0	Steel	140.0	14	0.78	4.167
P-135	150.0	Steel	140.0	14	0.78	4.162

P-136	150.0	Steel	140.0	11	0.63	2.802
P-137	150.0	Steel	140.0	11	0.63	2.806
P-138	150.0	Steel	140.0	3	0.15	0.205
P-139	150.0	Steel	140.0	3	0.15	0.198
P-140	150.0	Steel	140.0	4	0.25	0.498
P-141	150.0	Steel	140.0	4	0.25	0.496
P-142	150.0	Steel	140.0	17	0.99	6.460
P-143	150.0	Steel	140.0	17	0.99	6.458

Bentley Water CAD
Bentley Systems, Inc. Haestad V8i (SELECTseries 6)
Debre Birhan water supply.wtg Methods Solution Center [08.11.06.58]

Appendix-3 Nodal demand

Label	External demand (L/s)	Pattern (Demand)	Zone
J-72	0.31	Hourly pattern	Zone – 1
J-7	0.59	Hourly pattern	Zone – 1
J-67	0.35	Hourly pattern	Zone – 1
J-66	0.55	Hourly pattern	Zone – 1
J-65	0.65	Hourly pattern	Zone – 1
J-60B	0.10	Hourly pattern	Zone – 1
J-60	0.28	Hourly pattern	Zone – 1
J-6	1.53	Hourly pattern	Zone – 1
J-59	0.29	Hourly pattern	Zone – 1
J-58B	0.27	Hourly pattern	Zone – 1
J-57	0.67	Hourly pattern	Zone – 1
J-54E	0.48	Hourly pattern	Zone – 1
J-54D	0.20	Hourly pattern	Zone – 1
J-54C	1.08	Hourly pattern	Zone – 1
J-54B	0.80	Hourly pattern	Zone – 1
J-54A	0.89	Hourly pattern	Zone – 1
J-54	0.85	Hourly pattern	Zone – 1

J-53	0.22	Hourly pattern	Zone – 1
J-52A	0.13	Hourly pattern	Zone – 1
J-52	0.23	Hourly pattern	Zone – 1
J-51	0.21	Hourly pattern	Zone – 1
J-5	0.35	Hourly pattern	Zone – 1
J-48	0.22	Hourly pattern	Zone – 1
J-47	0.46	Hourly pattern	Zone – 1
J-46	0.11	Hourly pattern	Zone – 1
J-41	0.20	Hourly pattern	Zone – 1
J-40	0.45	Hourly pattern	Zone – 1
J-4	1.37	Hourly pattern	Zone – 1
J-39	0.46	Hourly pattern	Zone – 1
J-38	0.50	Hourly pattern	Zone – 1
J-37	0.33	Hourly pattern	Zone – 1
J-36A	0.18	Hourly pattern	Zone – 1
J-36	0.44	Hourly pattern	Zone – 1
J-35	0.16	Hourly pattern	Zone – 1
J-34	0.27	Hourly pattern	Zone – 1
J-33	0.81	Hourly pattern	Zone – 1
J-31	0.32	Hourly pattern	Zone – 1
J-30A	1.14	Hourly pattern	Zone – 1
J-30	0.96	Hourly pattern	Zone – 1
J-3	0.24	Hourly pattern	Zone – 1
J-28	0.68	Hourly pattern	Zone – 1
J-27	0.57	Hourly pattern	Zone – 1
J-26	0.68	Hourly pattern	Zone – 1
J-25	0.22	Hourly pattern	Zone – 1
J-24	0.30	Hourly pattern	Zone – 1
J-23	0.19	Hourly pattern	Zone – 1
J-225	0.84	Hourly pattern	Zone – 2
J-221	0.28	Hourly pattern	Zone – 2

J-22	0.76	Hourly pattern	Zone – 2
J-217	1.15	Hourly pattern	Zone – 2
J-216	0.29	Hourly pattern	Zone – 2
J-215	0.52	Hourly pattern	Zone – 2
J-214	0.52	Hourly pattern	Zone – 2
J-212	0.77	Hourly pattern	Zone – 2
J-211	1.12	Hourly pattern	Zone – 2
J-210B	1.17	Hourly pattern	Zone – 2
J-210A	3.04	Hourly pattern	Zone – 2
J-210	1.54	Hourly pattern	Zone – 2
J-21	0.27	Hourly pattern	Zone – 1
J-208A	1.24	Hourly pattern	Zone – 2
J-208	1.00	Hourly pattern	Zone – 2
J-18	1.51	Hourly pattern	Zone – 2
J-17	0.56	Hourly pattern	Zone – 2
J-167G	0.31	Hourly pattern	Zone – 2
J-167F	0.19	Hourly pattern	Zone – 2
J-167E	0.08	Hourly pattern	Zone – 2
J-167D	0.59	Hourly pattern	Zone – 2
J-167C	0.57	Hourly pattern	Zone – 2
J-167B	0.33	Hourly pattern	Zone – 2
J-167A	0.48	Hourly pattern	Zone – 2
J-163	0.40	Hourly pattern	Zone – 1
J-16	0.15	Hourly pattern	Zone – 1
J-159A	0.23	Hourly pattern	Zone – 2
J-133	0.55	Hourly pattern	Zone – 2
J-127A	0.94	Hourly pattern	Zone – 2
J-127	0.58	Hourly pattern	Zone – 2
J-124	0.35	Hourly pattern	Zone – 2
J-123	1.02	Hourly pattern	Zone – 2
J-122	0.63	Hourly pattern	Zone – 2

J-121	0.29	Hourly pattern	Zone – 2
J-120	0.42	Hourly pattern	Zone – 2
J-114A	0.46	Hourly pattern	Zone – 2
J-114	0.91	Hourly pattern	Zone – 2
J-113	0.54	Hourly pattern	Zone – 2
J-112	0.32	Hourly pattern	Zone – 2
J-111	0.72	Hourly pattern	Zone – 2
J-109	0.63	Hourly pattern	Zone – 2
J-107	0.43	Hourly pattern	Zone – 2
J-105C	0.50	Hourly pattern	Zone – 2
J-105B	0.47	Hourly pattern	Zone – 2
J-105A	0.10	Hourly pattern	Zone – 2
J-105	0.49	Hourly pattern	Zone – 2
J-104	0.87	Hourly pattern	Zone – 2
J-102B	0.43	Hourly pattern	Zone – 2
J-102A	0.05	Hourly pattern	Zone – 2
J-102	0.41	Hourly pattern	Zone – 2
J-102	20.00	Hourly pattern	Zone – 2

Appendix- 4- population and demand projection

		Year			
Population/Service Levels	Unit	2015	2020	2025	2030
Population	No	155,515	190,119	231308	278,726
Percentage of Population					
Served by:-					
HC	%	13.38	16	18.48	21.42
YC	%	41.84	48.5	56.23	65.19
PF	%	44.33	35.5	25.29	13.39
Population by Service Level					
HC	No	21500	30419	42746	59703
YC	No	65070	92208	130064	181701
PF	No	68945	67492	58498	37321
Per Capita Demand					
HC	Lpcd	65.5	75.9	88	102
YC	Lpcd	36.5	42.31	49.05	56.87
PF	Lpcd	25	27.6	30.47	33.65
Demand by Service Standard					
HC	m^3/d	1408	2309	3,712	6090
YC	m^3/d	2375	3901	6,380	10333
PF	m^3/d	1724	1863	1782	1256
Total water demand	m^3/d	5507	8073	11,874	17679
Climatic Factor 0.9	Combined				
	Factor			0.945	
Socio-economic Factor 1.05					
Adjusted Domestic Water Demand	m^3/d	5204	7629	11221	16707
Institutional and commercial demand	10%	520	763	1122	1671
Industrial water demand	10%	520	763	1122	1671
Firefighting demand	5%	260	381	530	835
Average daily water demand	m^3/d	6504	9536	13995	20884
Unaccounted water demand	25%	1626	2384	3499	5221
Projected average water demand	m^3/d	8130	11920	17494	26105
Maximum day factor	1.2	1.2	1.2	1.2	1.2
Maximum daily water demand	m^3/d	9756	14304	20993	31326
Peak hour factor	1.6	1.6	1.6	1.6	1.6
Peak hour demand	m^3/ hr.	650	954	1400	2088

Appendix -5 Model evaluation using regression

ID	**X(Pred)**	**Y(Obs)**	**Y-X**	**Y-Y_{avg}**	**X-X_{avg}**	**$(Y-X)^2$**	**$(Y-Y_{avg})^2$**	**$(X-X_{avg})^2$**	**$(X-X_{avg})$ $(Y-Y_{avg})$**
1	14.05	13.75	-0.3	-6.043	-6.34	0.09	36.524	40.15	38.29463775
2	18.355	17.83	-0.53	-1.964	-2.032	0.276	3.86	4.13	3.98885025
3	20.38	18.8	-1.58	-0.994	-0.007	2.496	0.987	0	0.00645775
4	32.075	32.63	0.56	12.84	11.689	0.308	164.7	136.62	150.0394303
5	17.49	12.825	-4.67	-6.97	-2.897	21.762	48.56	8.39	20.18426025
6	12.17	12.46	0.29	-7.334	-8.22	0.0841	53.78	87.51	60.25570275
7	24.6	22.83	-1.77	3.0365	4.2135	3.133	9.22	17.754	12.79429275
8	12.26	11.86	-0.4	-7.934	-8.13	0.16	62.94	66.04	64.47158775
9	7.445	9.53	2.09	-10.26	-12.94	4.347	105.34	167.482	132.8250853
10	45.04	45.42	0.38	25.63	24.653	0.1444	656.72	607.795	631.7829178
avg	20.3865	19.7935	-0.59			3.2801	114.2631	113.5871	111.4643223
sum	203.865	197.935	-5.93			32.801	1256.894	1135.871	1114.643223

The value of the coefficient of determination (R^2) is computed using the formulae:

$$R^2 = \frac{\sum (x - x_{avg.}) * (y - y_{avg.})}{\sqrt{\sum (x - x_{avg.})^2} \quad * \sqrt{\sum (y - y_{avg.})^2}} = 0.98$$

The regression model statistics accounts for 98% of the variance indicates a strong linear relationship between simulated and observed values.