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JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING

MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

# EVALUATING HYDRAULIC PERFORMANCE OF WATER SUPPLY DISTRIBUTION NETWORK: A CASE OF ASELLA TOWN, ETHIOPIA

By: Shambel Belachew

A thesis submitted to School of Graduate Studies, Jimma Institute of Technology, faculty of civil, and Environmental Engineering, hydrology and hydraulic Engineering chair in partial fulfilment of the requirements for the degree of Master of Science in Hydraulic Engineering

January, 2021

Jimma, Ethiopia

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Main advisor: Dr. Dawud Temam (Ph.D)

Co-advisor: Mr. Tadele Shiferaw (MSc)

January, 2021

Jimma, Ethiopa

## DECLARATION

I, the undersigned, declare that this thesis entitled **Evaluating Hydraulic Performance of Water Supply Distribution Network: A Case of Asella 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. .

| | | |
|---|---|---|
| Shambel Belachew | ____________________ | ___________________ |
| Candidate | Signature | Date |

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

| Name | Signature | Date |
|---|---|---|
| 1. Main-advisor | | |
| Dr.Dawud Temam (PhD.) | ________________ | ______________ |
| 2. Co -advisor | | |
| Mr. Tadele Shiferaw (MSc.) | ________________ | ______________ |

# APPROVAL SHEET

The thesis entitled "(EVALUATING HYDRAULIC PERFORMANCE OF WATER SUPPLY DISTRIBUTION NETWORK: A CASE OF ASELLA TOWN, ETHIOPIA)" submitted by Shambel Belachew is approved and accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering at Jimma Institute of Technology.

Name Signature Date

Main Advisor: Dr. Dawd Temam ____________ _______________

Co-advisor: Mr.Tadele Shiferaw (M.Sc.) _____________ _______________

As members of the examining Board of MSc. thesis, we certify that we have read and evaluated the thesis prepared by SHAMBEL BELACHEW. We recommend that the thesis could be accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

Name Signature Date

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Internal Examiner

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# ABSTRACT

*Population growth exploitation in the town usually exerts enormous pressure on existing water supply systems. The continuous and repeated deficiency in the performance of the water network becomes one of the most critical issues in the water supply sector that requires immediate action. Asella town water supply system has problems related to water supply coverage, water quantity, velocity, and system pressure. The main objective of this study is to evaluate the hydraulic performance of Asella town's existing water supply distribution system with respect to pressure and velocity using Bentley Water GEMS v8i software. Both primary and secondary data were collected and software such as Bentley Water GEMS v8i software, ArcGIS version10.1, Microsoft office Excel, and Geographic positioning system Garmin72 (GPS) were used. The average daily per capita water consumption and water supply coverage of the town in 2020 G.C is 35.31 l/p/d and 42.249% respectively. The simulated result for extended period simulation at peak hour consumption showed that the performance of distribution system related to pressure 47.08% for pressure value (<15m), 32.92% for pressure value (15-60m) and 20% for pressure value (>60m) head and the pressure at minimum consumption hour is 10% for pressure value (<15m), 45.85% for pressure value (15-60m) and 44.15% for pressure value (>60m. The velocity of pipe flow at peak hour consumption showed that 79.56% for velocity (<0.6m/s), 14.09% for velocity range (0.6-2m/s) and 6.35% for velocity (>2m/s). From the total 650 nodes in the model, 306 nodes receive water with less than 15m pressure head of water and it indicates the critical point showing that needs a modification. The average annual water loss in Asella town is 35.24% showing that needs a matter of concern. The amount of water which actually reached the consumers in average from 2016 G.C to 2020 G.C is 64.76% of the total annual water production. It is recommended that, the water utility have to be add new water source to deliver adequate water and add parallel pipes or increasing its diameter to deliver water with the required pressure.*

**Key Words:** Asella Town, Hydraulic Model, Water Distribution Network, and Water GEMS

# ACKNOWLEDGEMENT

I would like to give thanks and praise God for His provision, grace and mercy in all the paths of my life who favoring me with health, knowledge, wisdom and courage to finalize my study and do this research.

I am grateful to my Advisor Dr**. Dawud Temam (Ph.D)** for his efforts, useful suggestions, and encouragements, which provided valuable guidance for me starting from proposal up to the whole thesis work. I am very grateful to express my sincere thanks to my co-advisor **Mr. Tadele Shiferaw (MSc)** for his-constructive comments, his guidance helped me in all the time writing of my thesis and guiding me on the right direction to- accomplish this work successfully.

I would like to express my gratitude to the staff of Asella Town water supply office that helped me a lot to get all required data and finally I would like to express my deepest gratitude to all my friends for those share supportive idea in doing the research.

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# ACRONYMS

| | |
|---|---|
| ADD | Average daily demand |
| AWSSE | Asella Water Supply and Sewerage Enterprise |
| AWWA | American Water Work Association |
| CIWD | Commercial and institutional water demand |
| CSA | Central Statistics Agency |
| CWT | Clear water tanks |
| DCI | Ductile Iron |
| DWD | Domestic water demand |
| GEM | Geospatial Engineering Model |
| GPS | Global Positioning System |
| GTP | Growth and Transformation Plan |
| IWD | Industrial water demand |
| l/c/day | Liter per Capita per Day |
| MDD | Maximum daily demand |
| MBR | Main Balance Reservoir |
| MoWR | Ministry of Water Resource |
| OWWDSE | Oromia Water Works Design And Supervision Enterprise |
| PVC | Polyvinyl chloride |
| RPS | Rural Piped Systems |
| SR | Service reservoir |
| UFW | Unaccounted for water |
| UNICEF | United Nations Children’s Emergency Fund |
| Vi8 | Version 8 |
| WDS | Water Distribution System |
| WHO | World Health Organization |
| WTP | Water treatment plant |

# 1. INTRODUCTION

## 1.1 Back ground

Water is one of the most essential commodities of every living being in the world. Globally, the population using piped drinking water supplies between 2000 and 2017 year is increased from 3.5 billion to 4.8 billion, this equates to an average of 85,000 people per day over a 17-year period (WHO/UNICEF, 2017). While over the same period, the population using non-piped drinking water supplies increased from 1.6 billion to 2.2 billion. In Ethiopia accessibility is equally low in rural (5%) and urban (72%) there is a 67 percentage point gap between rural and urban areas (UNICEF/WHO, 2017).

According to second Growth and Transformation Plan (GTP-2) the goal were set to Provide rural water supply access with minimum service level of 25 l/c/day within a distance of 1 km from the water delivery point for 85% of the rural population of which 20% are provided with RPS and to Provide urban water supply access minimum service level of 100 l/c/day for category-1 towns/cities, 80 l/c/day for category 2 towns/cities, 60 l/c/d for category-3 towns/cities, 50 l/c/day for category-4 towns/cities, up to the premises and 40 l/c/day for category-5 towns/cities within a distance of 250 m with piped system for 75% of the population (MoWIE, 2019). The total average daily per capita water consumption of the Asella town is 35.31 l/c/day which is very low as compared to the value set by MoWIE (2019) for second Growth and Transformation Plan (GTP-2) which 60 l/c/d for category-3 town.

Water distribution systems can be either looped or branched. Looped systems are generally more desirable than branched system because, in the looped system, breaking of pipe can be isolated and repaired with little impact on consumers outside the immediate area. On the other hand, in the branched system, all the consumers downstream from the break will have their water supply interrupted until the repairs are finished (Atiquzzaman, 2004). Water distribution systems are required to supply water to domestic, commercial, and industrial entities above or at a threshold pressure with consumer demands that vary throughout the day, weak, season and year. The minimum pressure that should be observed at junctions throughout the system varies depending on the type of water consumption (Hopkins, 2012).

According to the report of Asella town water supply service enterprise the existing Asella town water supply system is defined as one pressure zone. The town has geodetic difference of about 550m, from south to north; necessitating for creation of pressure zoning of the distribution network and hence resulted in unbalanced supply from the existing distribution network. Due to the low pressure of water in the distribution network, consumers at relatively higher spots and expansion areas of the town cannot get water.

Models are used to predict pressures under specific demand conditions and under a wide variety of scenarios to identify low pressures and to select infrastructure that will improve flow or less pressure deficiency (AWWA, 2017). Hydraulic modeling simplifies the analysis of water distribution system and it helps to predict uncertainties in present and future demands of existing distribution systems (Udhane et al., 2018). In Assella town damaged water pipe and topography of the area are the major problems which can cause low water pressure and uncertainty of water demand in existing water supply distribution system. So to increase the sustainability, evaluation of hydraulic performance in the distribution system is significant.

## 1.2 Statement of problems

Many countries in the world are entering an era of severe water shortage and about a billion of people in developing countries have not safe, reliable, affordable, easily accessible and sustainable water supply (WHO, 2011; Hunter *et al*., 2010). In developing countries like Ethiopia urban water distribution systems designed for continuous water supply at adequate pressure and flow however, often operated intermittently. Because of the rapid increase in population, urbanization make high pressure on existing infrastructure, which usually results in infrastructural decay, there by disrupted the efficient water distribution system. Moreover, urban water supply networks are large-scale systems that transport potable water over vast geographical areas to millions of consumers. As a result, water supply networks regularly experience pressure drops and interruptions of water supply. When there is an unexpected increase in water demand, then evaluating hydraulic performance for safe and efficient operation of these networks is crucial (Gottipati and Nanduri, 2014).

Asella town is suffering from the discontinuous supply of water in the distribution systems. 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 does 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. The town water supply system has low water supply coverage and high water loss. Therefore, evaluating the hydraulic performance of water supply distribution system of the town was paramount importance to upgrade the distribution system or add new resource to meet current and future demand.

This study was undertaken using Bentley water GEMS 8Vi and the existing water distribution network was simulated for extended period simulation analysis to evaluate the performance of the system related to pressure and velocity and its outlook to provide base line information for decision makers and further research.

## 1.3 Objectives of the study

### 1.3.1 General objective

The general objective of this study is to evaluate the hydraulic performance of water supply distribution system of Asella town.

### 1.3.2 Specific objectives

1. To evaluate water supply coverage and water losses of existing water distribution system of Asella town.
2. To analyses hydraulic parameters and identify the location of critical points of existing water distribution system of Asella town.

## 1.4 Research Questions

1. Is there available water for domestic consumer and water loss in the water distribution network of Asella town?
2. What seems Asella town in analyzing the hydraulic parameters in the existing water distribution system?

## 1.5 Significance of study

From this study it is expected that the pressure variations in the existing water supply distribution network is monitored by using hydraulic modelling software. Hence, this study is used as significant input to Asella town water work sector to re consider their system and to take necessary modifications in order to convey water to the users with adequate pressure. The study findings is also intended to help implementers, as well as policy makers, planners and donors, in water sector as working document and benchmark data for any further investigation.

## 1.6 Scope and Limitations of the Study

The scope of this study is primarily focus on evaluating performance of the existing water supply distribution system in terms of pressure and velocity comparing with recommended system design criteria, water supply coverage and water loss based on comparison of the total volume of water utility produced and total volume of water consumed for which the utility collects revenue. This study was used hydraulic network analysis software Bentley WaterGEMSV8i software. The performance of the system was observed under peak consumption and minimum time consumption and its performance was evaluated based on hydraulic conditions not including water quality.

# 2 LITERATURE REVIEW

## 2.1 Water Supply Distribution Networks

The aim of water distribution systems (WDSs) is to safely deliver adequate quantities of drinking water to end users under sufficient pressures. In design, the system pressure is generally to be maintained between minimum and maximum acceptable levels for safe, reliable and economic operation. High pressure systems tend to cause more frequent pipe breaks and an increase in energy use and leakage (Ghorbanian *et al*., 2015). The maximum permissible pressure is determined according to pipe's strength which is related to its material, wall thickness and general condition. Low pressure systems cause consumer complaints, make the system more susceptible to negative pressures

Water distribution network consists of a system of pipes or links through which the water flows, connected together at nodes which may be at different elevation. A node usually has one of the two main functions; it either receives a supply for the system or it delivers the demand required by consumers (Piplewar and Chavhan, 2013). Rising water demand as a result of population growth and urbanization has an effect on the availability and reliability of existing water distribution system. Therefore, water demands need to be assessed on the basis of considering the year and date supplying water through the distribution system. Several hydraulic modeling approaches have been proposed previously to simulate pressure - deficient operating conditions in water distribution networks more realistically (Hunde and Itefa, 2020).

## 2.2 Methods of Water Supply System

The primary task for water utilities is to deliver water of the required quantity to individual customers in continuous supply system or intermittent supply system under sufficient pressure through a distribution network (Mehta *et al*., 2017, Rao *et al*., 2015).

### 2.2.1 Continuous System

Continuous Water supply is said to be achieved when water is delivered continuously to every consumer of the service area, 24 hours a day, every day of the year, through a transmission and distribution system that is continuously full and under positive pressure (Rao *et al*., 2015).

Continuous water supply system is the best system and water is supplied for all 24 hours and 7 days in a week. This system is possible when there is adequate quantity of water for supply. In this system, supply water is always available for firefighting. In addition, due to continuous circulation, water always remains fresh. In this system less diameter of pipes are required and rusting of pipes will be less. Losses will be more if there are leakages in the system. The distribution system remains continuously pressurized so that no contaminated ground water can enter into the water pipelines even there are some small leakages in the system (Mehta *et al*., 2017).

### 2.2.2 Intermittent System

“Most developing countries have intermittent water supply and sometimes a large quantity of water is received by only a few zones or consumers, leading to inequitable water supply.” Access to water in an intermittent system can range from predictable to unreliable, and this distinction can have serious implications for consumers (Galaitsi *et al*., 2016). Intermittent supply can be caused by insufficient water resources, inadequate infrastructure, unplanned expansion of the distribution network, excessive water losses, or a combination of those factors (Erickson, 2016).

In Intermittent System water is supplied at regular intervals throughout the day. Water may be supplied for a few hours in the morning or in the evening. Due to some negative pressure, the quality of water is not so good compared to continuous water supply system. This system may cause serious risk to health as a result of ingress of contaminated ground water into the distribution system (Mehta *et al*., 2017).

## 2.3 Types of water transmission or distribution system

Usually, treated water is conveyed to service reservoirs for distribution to consumers. In urban systems, a water transmission system may also be necessary to convey water from a treatment plant to a number of service reservoirs located at different convenient points in the city. In some cities, there may be a number of sources and water treatment plants supplying service reservoirs and water distribution systems. These distribution systems may be separate or linked (WHO, 2014).

Both water transmission systems and water distribution systems are networks of pipes. However, water transmission systems have a tree-like configuration, whereas water distribution systems usually have loops. Sometimes, supply of water from the clear water tank at the treatment plant to various service reservoirs is by gravity. Often, treated water is either pumped directly to various reservoirs or pumped to a main balancing reservoir, which, in turn, supplies water to various service reservoirs by gravity. Such systems are termed complete gravity, direct pumping and combined gravity and pumping systems, respectively (WHO, 2014).

## 2.4 Layouts of Pipe Networks

In the water distribution networks the street patterns, topography, construction plans and future plans determine the layout of pipes. The distribution pipes are generally laid below the road pavements, and as such their layouts generally follow the layouts of roads (Abdur Raheman and Vaghani, 2018)**.**

A branched network, or a tree network, is a distribution system having no loops. In the branched or tree system one main pipe line goes through the center of populated area and sub-main branch off from both sides. This system is easy to lay. However, in case of failure in pipeline, it will be difficult to supply water to the area ahead of affected area. Also pressure at the tail end is low compared to other area and there is stagnation of water. For repair of pipe the whole branch cannot deliver water in branch systems

A pipe network in which there are one or more closed loops is called a looped network. Looped networks are preferred from the reliability point of view. If one or more pipelines are closed for repair, water can still reach the consumer by a circuitous route incurring more head loss. On the other hand, the branched pipe networks do not permit the water circulation since they contain lots of dead ends. For repair of pipe the whole branch cannot deliver water in branch systems. Asella town water distribution systems are a combination of looped and branched systems.

## 2.5 Urban Water Supply Coverage

Water supply coverage provides a picture of the water supply situation of one specific country or city and helps to compare one country with others and the inter and intra city distribution with in specific country. The percentages of population with or without piped water connection are a relevant indictor to compare the coverage of water supply in urban areas (Melaku, 2015).

In evaluating the water supply coverage the focus was on the volume of consumption and level of water connection as these are highly related to the issue of water loss. After evaluating the distribution of water supply coverage in the town, the water loss from the distribution system of the utility was analyzed (Asmelash, 2014).

## 2.6 Performance Measurements of Water Distribution System

The major challenges of urban water supply systems in developing countries are low water supply service coverage, unavailability of sufficient water at all times, very high amount of water loss which ranges up to 50% of amount of water produced and absence of quality water which meets national or international drinking water standards (Desalegn, 2015).

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. 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 is evaluated based on three performance measures: Hydraulic, Structural, and Customers perception.

### 2.6.1 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 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 (Desalegn, 2015).

### 2.6.2 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 (Salmivirta, 2015).

### 2.6.3 Customer perception

In order to evaluate a WDS, it is 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 (Salmivirta, 2015).

## 2.7 Estimating urban water demands

There are so many factors involved in determining of demand that make the actual demand estimation unreliable. However, the demand for various purposes is divided under the following categories: Domestic water demand, Non-domestic water demand, Business or commercial water demand, Industrial water demand and Fire water demand (Koritsas, *et a*l., 2018).

Domestic water demand is the quantity of water required for In-house drinking, cooking, ablution, sanitation, house cleaning, car washing, clothes washing; Sprinkling of garden and lawn. Institutional water demand is the quantity of water required for schools, hospitals, universities, government and nongovernment offices etc. industrial water demand is the quantity of water required for factories, industries, power stations, docks. Commercial water demand is the quantity of water required for shops, offices, restaurants, small trades etc.

Public water demand is the quantity of water required for street watering, public parks, sewer flushing, firefighting (Demo, 2010)

### 2.8 Water Losses in Distribution System

The volume of water lost between the point of supply and the customer meter due to various reasons. The most basic way to determine losses is to calculate the difference between the system input and output. These losses can be divided into “apparent losses” and “real losses”. Apparent losses are caused by unauthorized consumption by illegal connections and metering inaccuracies. Real losses are caused by leakage and overflows. The term unaccounted for water (UFW) describes the combination of real and apparent losses. Water losses occur in every water distribution network in the world. For economic and technical reasons, it has to be accepted that real water losses cannot be eliminated (Sarkar, 2017).

Leakage from the water distribution pipeline network can be defined as that water which, having been obtained from the source, treated and put into supply, leaks and escapes other than by a deliberate action. In India, much of transported water is lost through leakage. This figure can be even higher for older pipes. The loss of such large volumes of water is environmentally and economically damaging (Sarkar, 2017).

### 2.9 Water Supply Distribution System Computer Modeling

Water distribution system modeling involves using a computer model of a water distribution system to predict the behavior of this system to solve a wide variety of design, operational, and water quality problems. The computer model is used to predict pressures and flows in a water distribution system to evaluate a design and to compare system performance against design standards. The model is used in operational studies to solve problems, such as evaluating water storage capacity, investigating control schemes, and finding ways to deliver water under difficult operating demand scenarios such as a major fire in the community or city (Harry E. Hickey, 2008)**.**

#### 2.9.1 Water GEMs software

After Water Cad, EPANET and loop, the most advanced and powerful software for designing water supply networks is Water GEMs software. It is the modified version of Water Cad software that is designed by Hasted and Bentley companies. It has a plenty of capabilities, from simulating the discharge of fire station and water quality to calculating the costs of energy and more advanced topics (Irandoust, 2016). Water GEMS V8i is hydraulic modeling software for water distribution systems with advanced interoperability, geospatial model building, and optimization and asset management tools. It provides an easy to use environment for engineers to analyze, design and optimize water distribution network from fire flow, water quality simulation and constituent concentration analysis to criticality, energy consumption and capital cost management (Udhane *et al*., 2018).

## 2.10 Hydraulic Design of Pipes

### 2.10.1 Head (Energy) Losses

A continuous resistance is exerted by the pipe walls during water flow. This resistance depends on the flow rate, pipe dimensions and internal roughness of the pipe material as well as from the fluid viscosity, and results in linear head degradation along the pipeline. A head-loss (energy) for a specified length is commonly referred to as friction loss. There are several formulae for calculation of head losses. The most frequently used in the design of water supply system are Darcy-Weisbach and Hazen Williams formulae (OWWDSE,2010).

### 2.10.2 Minor Losses

Minor losses are a result of localized areas of increased turbulence and are frictional head losses, which cause energy losses within a pipe. A drop in the energy and hydraulic grades caused by valves, meters, and fittings, the value of these minor losses is often negligible relative to friction and for long pipes, and they are often ignored during analysis. Minor head losses (also referred to as local losses) can be associated with the added turbulence that occurs at bends, junctions, meters, and valves, enlargers, reducer. The importance of such losses will depend on the layout of the pipe network and the degree of accuracy required. Minor losses can be calculated by multiplying the velocity head by a minor loss coefficient (Hopkins, 2012).

## 2.11 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 (Zyoud, 2003). The hydraulic modeling was performed to evaluate the adequacy of existing facilities for conveying current flows. Pressure and velocity are the hydraulic parameter analyzed by computer modeling to identify system deficiencies. According to MoWR(2006) the target minimum system operating pressure is 15m water head at normal conditions and 10m water head at exceptional conditions. According to the above pressure criteria, the pressures below the minimum system of operating pressure were identified as critical point.

### 2.11.1 Pressure

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

### 2.11.2 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. Low velocities affect the proper supply and will be undesirable for hygienic reasons (sediment formation may cause due to the longtime of retention) (Zyoud, 2003).

## 2.12 Water Model Analysis

### 2.12.1 Steady-State Analyses

Steady-state simulation is the simplest simulation type and solves the system of equations as if the system is in equilibrium. In other words, the dynamic variables such as pipe flows, junction demands, and tank elevations are kept constant (Hopkins, 2012). A steady-state simulation provides a snapshot of pipe system conditions at any instant in time and are commonly used to model peak demands or a short time period (AWWA, 2017).

### 2.12.2 Extended-Period Simulation

An extended-period simulation is a series of steady state simulations executed at specified intervals and performed over a specified time period. This capability may be used, for instance, to model the operation of a water system over a 24-hour period. Such a simulation is useful in modeling variations in demand, reservoir operations, water quality, emergency responses, energy management, and water transfers through transmission pipelines. Extended-period simulation requires that the modeling software model flow and pressure variations, incorporate diurnal water demand patterns, simulate operational controls for pumps and control valves, and allow for varying tank configurations (AWWA, 2017).

## 2.13 Troubleshooting A Model

Models are used to troubleshoot potential causes of various problems such as low pressure, water circulation issues, and events that would otherwise be inexplicable (AWWA, 2017). Hydraulic models can be used to identify where, when and how low or negative pressures may occur in the distribution system by troubleshooting the results.

### 2.13.1 Low Pressure Problems

The most frequently occurring operational problem associated with water distribution systems is low or fluctuating pressures. Although confirming that the problem exists is usually easy, discovering the cause and finding a good solution can be much more difficult (Walski *et a*l., 2003).

#### *2.13.1.1 Identifying the Problem*

Identifying system problems may not be as easy as you might anticipate. For example, a low-pressure zone could be evident from simulation runs and you might think correctly “pipe diameter”, but which one? You might identify a pipe with a high velocity and assume that is the culprit. So you increase the pipe diameter and find the problem has been worsened or is unchanged (Gilbert, 2012)**.**

Customer complaints, modeling studies, and field measurements obtained through routine checks can indicate that a portion of the system is experiencing low pressure. The pressure problem can be verified by connecting a pressure gage equipped with a data logging device. Occasionally, a customer may report a low-pressure problem when the pressure at the main is fine. In such cases, the low pressure may be due to a restriction in the customer’s plumbing, or a point-of-use/point-of-entry device that is causing considerable head loss (Walski *et al.*, 2003).

If measurements indicate that pressure in the main is low and a problem in the distribution system is suspected, the next step is to examine the temporal nature of the problem. Pressure drops that occur only during periods of high demand are usually due to insufficient pipe or pump capacity, or a closed valve. If the problem occurs at off-peak times, nearby pumps may be shutting off once remote tanks have been filled, lowering the pressure on the discharge side of the pumps (Walski *et al.*, 2003).

### 2.13.2 High Pressure

As with low pressure caused by increased grade, a high pressure zone may be present if the grade falls. The pressure then increases 0.43 psi with each foot of fall. An operating pressure of 80 psi may experience water hammer or surges well above 80 psi, damaging household plumbing or plumbing fixtures. Check your system and make necessary adjustments either lowering the high tank elevation or using a PRV (Gilbert, 2012).

In the case of high pressure problems, pipe diameters that are too large cannot be identified. There are fiscal considerations for using the correct pipe diameters. In fact, as the design engineers it is your obligation to design a system with the optimum pipe diameters. In addition to the cost associated with oversized pipes, there is the concern for chlorine dissipation from long travel times. There really is no room for factors of safety especially when considering the cost of capital improvements and your ability with modeling software to substantially simulate real world conditions. If you suspect your pipe diameters are too large, reduce them and run the simulation again. Continue the process throughout the system until the system is at its optimum design (Gilbert, 2012).

# 3 MATERIAL AND METHODS

## 3.1 Description of the study area

Asella town is situated in the Arsi Zone, being the zonal capital, at a road distance of 175km from Addis Ababa or 75km from Adama town. It is accessed through asphalt road running from Addis Ababa via Adama to Bale Robe. The town is bounded by geographical coordinates between UTM 39$^{0}$7’0”E to 39$^{0}$9’0”E longitude and 7$^{0}$54’30”N to 7$^{0}$58’30”N latitudes.

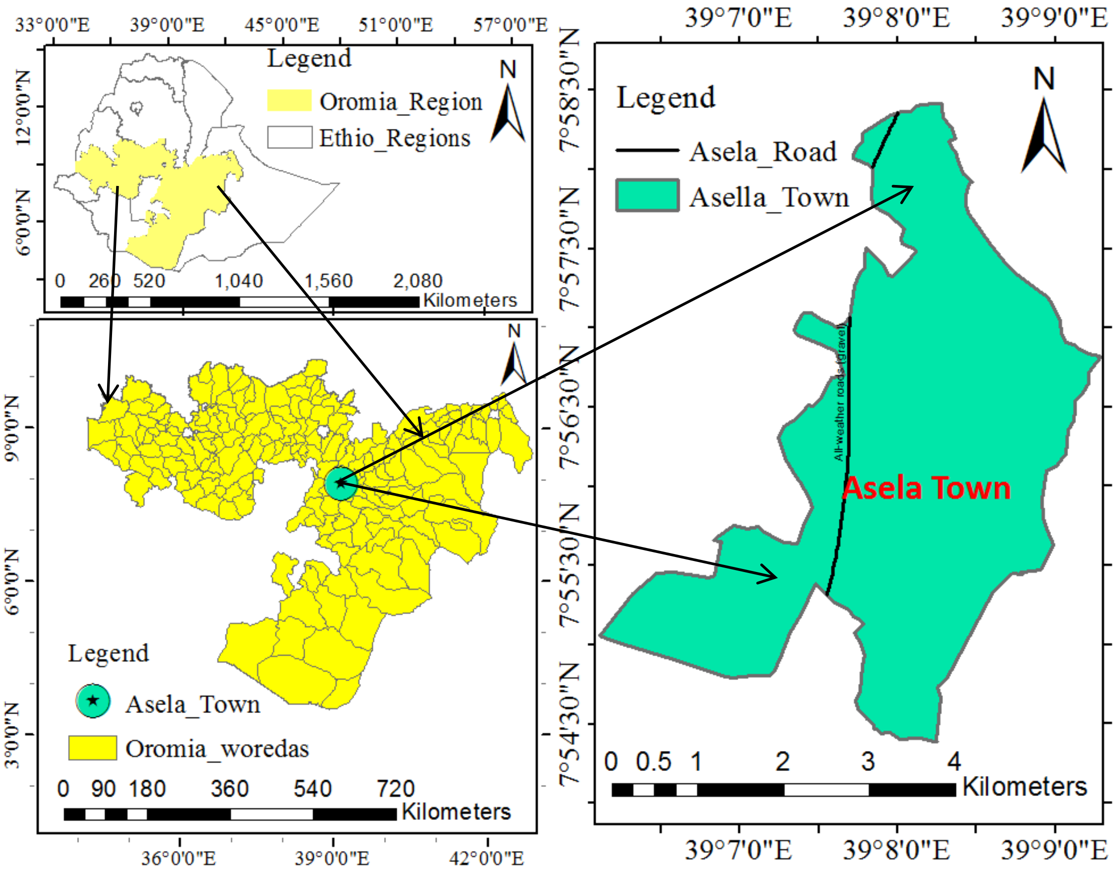


Figure 1: Map of the study area (adopted from ArcGIS)

### 3.1.1 Topography of the study Area

The study area and its surrounding are characterized by plain highland plateau and it is bounded by Awash and Rift valley river basin in the NE and E respectively. North-South elongated volcanic mountain chain/Chilalo mountain marks the watershed divide between the rift valley lakes and Awash rivers basin (Asella Urban Planning Office, 2009).

### 3.1.2 Climate

Based on elevation variation above mean sea level the climate of the catchment comprising Asella town is categorized under Woinadega to Dega ecological zone of the country. According to the meteorological data, the average annual rainfall of the area varies spatially from about 617mm in lowland to over 1167mm at highland areas. The mean daily temperature recorded also varies between 13.10C and 15.60C at Asella station (Asella Urban Planning Office, 2009).

### 3.1.3 Study variables

The study variables are variable that going to be evaluates and the output in the study period. These variables are two types independent and dependent variables independent variables mainly related with the specific objective of the study. The main independent variable considered in these studies is Pressure, Flow rate and Velocity. The dependent variables those, that are the output of the finding. These depend on the independent variables, such as, the output of hydraulic simulation, efficient and identification of the location of critical points in the in the water distribution system like low pressure.

## 3.2 Materials used

### 3.2.1 Equipment

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

### 3.2.2 Software: Water GEMS

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

Bentley water GEMS V8i is selected for this study because of the following reason:- Graphical user interferences and latest as compare to Epanet software, integration with external software, like Auto CAD and ArcGIS and requires less effort and shorter time to build a model than others.

### 3.3 Data collection

The data collection process was performed using both primary and secondary data collection techniques to get the required information. Water production and consumption data used to evaluate water losses and water supply coverage of the town. Survey, design data and the town existing water distribution network layout were used to construct the model using Water GEMS v8i software and the pressure for ten sample nodes was measured by using pressure gauge to calibrate the model. All the necessary data type and their respective sources are listed in the table 1 below.

Table 1: Data type and source

| **S.No.** | **Data type** | **Source** |
|---|---|---|
| 1 | Water production and consumption data | Asella Water Supply and Sewerage Enterprise |
| 2 | Survey and design data of the existing water supply distribution | Asella Water Supply and Sewerage Enterprise |
| 3 | The town existing water distribution network layout | Asella Water Supply and Sewerage Enterprise |
| 4 | Ortho-image of Asella town | Asella town land administration office |
| 5 | Population Data | Central Statistical Agency |
| 6 | Observed Pressure data (the data which used for model calibration) | Field measurement observation |

#### 3.3.1 Water sources

The current production of water supply for Asella town depends on Ashebeka River, which are administrated by Asella town water supply and sewerage enterprise. The present total hourly Ashebeka raw water prop osed to be delivered to the balancing chamber is about 350m$^3$/hr (8400 m$^3$/day) which is very far behind the required water demand of the town. The actual production of water has lower than the maximum capacity. Production data computed for Ashebeka rivers discharge shows that actual production of water at present from the system was 5673.02 m3/day, which is 67.54% of its capacity (8400 $m^3$/day).

### 3.3.2 The town existing water distribution network

The existing water supply source for the Asella towns is water from Ashebeka River. The water from Ashebeka River is taken to Asella town both through gravity and pumping systems at its upstream and far downstream section of the river. The entire town water supply distribution network including their attribute like pipe length, diameter, material types, roughness coefficient of the pipes, Junction point, pumps characteristics, reservoir and tank section. Operational parameters, which indicate the actual value of system facilities, such as flow rates, overflow and bottom elevations of network for pressure zones is collected from the Asella town water supply and sewerage Enterprise office.

### 3.3.3 Water production and Consumption of Asella town

The recorded trend of water production and consumption for five consecutive years (2016-2020G.C) was collected from Asella town water supply and sewerage Enterprise office. As per the data obtained regarding water production and consumption, it is observed that the production rate varies from year to year as shown in table 2 below.

Table 2: Annual water consumption and production records

| Description | Unit | year ( E.C) | | | | |
|---|---|---|---|---|---|---|
| | | 2016 | 2017 | 2018 | 2019 | 2020 |
| Volume of Water Produced | $m^3$ | 2,166,733.00 | 2,191,630.00 | 2,430,260.00 | 2,327,255.00 | 2,070,653.00 |
| Volume of Water Sold | $m^3$ | 1,480,466.00 | 1,421,963.00 | 1,380,367.00 | 1,382,691.00 | 1,204,939.00 |
| Volume of Water used for other | $m^3$ | 71,108.00 | 72,074.00 | 95,341.00 | 79,685.00 | 46,867.00 |

Water production of Asella town is decrease from 2018 to 2020 G.C due to the following reasons:

I. **Reduction in yield of water source**: frequent reduction in the yield of Ashebeka gravity main associated with global climatic change, change in land use and land cover around the spring eyes forming river and over the entire catchment, and use of Ashebeka river for traditional irrigation practices upstream of the gravity main intake site making the river course dried up particularly during dry season.

II. **Absence of Source Protection**:- The current trend of farming practices over the entire upstream Ashebeka river catchment is susceptible to cause contamination reduction in river discharge and causes contamination from agro-chemicals. Same way eucalyptus vegetation through destruction of natural vegetation in the entire river catchment upstream of the intake sites are impart negative impact and great reduction on the river discharge.

### 3.3.4 Population data

The water demand of a particular town is proportionally related with the population to be served. According to 2015 Asella town Administration Office report the total population of 78,722 persons was used as base population for current estimation. Using the exponential population forecasting method, the estimated total population figure of Asella town was 97118 in 2020.

Table 3: Population projection based on 2007 CSA

| Year | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Growth rate (%) | 4.10 | 4.00 | 3.80 | 3.50 | 3.30 | 3.00 |
| Population | 78722 | 97118 | 118620 | 143441 | 171730 | 203552 |

## 3.4 Data analysis

Primary and secondary data can be analyzed both qualitatively and quantitatively. Qualitatively, data’s are analyzed with the help of tables, charts or in words and quantitative data was analyzed with the help of Bentley Water GEMS v8i software. GPS and Arc map 10.1 is used to collect data and to generate map of the study area respectively. Qualitatively data was interpreted with the help of Microsoft Excel. The volume of water consumed for domestic purpose is estimated by converting the annual consumption data to average daily per capita consumption using the projected total population figure during (2020 G.C).

### 3.4.1 Water supply coverage analysis and Water Loss Analysis

#### *3.4.1.1 Water supply coverage analysis*

Water supply coverage is usually evaluated based on the quantity, quality, paying capacity of the people, distance, etc., but the intention of this study is not to evaluate all these but related to the quantity of supply that which is related to the imbalance between supply and consumption of water to the town. In this part of the analysis, the average daily per capita consumption is used to analyze the water supply coverage for the entire study area.

The volume of water consumed for domestic purpose is estimated by converting the annual consumption data to average daily per capita consumption using the projected total population figure during (2020 G.C). The following formula was applied for the determination of per capita consumption (liter/person/day) (Desalegn, 2015).

$$\text{per capital water consuption} = \frac{\text{Annual consuption } (\text{m}*^{3}*1000\frac{\text{l}}{\text{m}^{3}}}{\text{Population}*365} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq.3.1)}$$

The water supply coverage of the town has been evaluated based on annual water production and annual water demand as follows:-

$$\text{Water supply coverage} = \frac{(\text{annual production}*100\ \%)}{\text{annual demand}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq.3.2)}$$

#### *3.4.1.2 Water Loss Analysis*

The water loss analysis of Asella town was evaluated in aggregated form in numerical as well as percentage of the Non-revenue water which was obtained from the total water production and water consumption. According to the data obtained from Asella town water supply and sewerage enterprise, the water loss in the town is identified by using the water production and water consumption (billed water volume) for five consecutive years starting from 2016 up to 2020 G.C.

Unaccounted-for-water is a term that has been historically used in the United States to quantify water loss from distribution systems. Unaccounted-for-water, expressed as a percentage, is calculated as the amount of water produced by the public water system minus the metered customer use divided by the amount of water produced multiplied by 100 as follow (EPA, 2010).

$$\text{Total water loss}(\%) = \frac{(\text{Total water produced} - \text{Total water billed}) * 100}{\text{Total water produced}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq.3.3)}$$

### 3.4.2 Model Representation

The model is constructed using Water GEMS software by giving all the necessary inputs collected from Asella town water supply distribution network layout, Pipe data such as pipe diameter (mm), C-value and length (m) are assigned to the network. Input for nodes are elevation (m), water demand (lps) and time pattern. Pump head (m) and flow (lps) are required data for the construction of pump curve. Figure 2 shows the constructed model of the water supply network from source to WTP and WTP to service reservoir.

The whole water supply area is in one pressure zone. Junctions and consumer connections are getting water from the 1000m$^3$ St.Merry Reservoir, 400m$^3$ St.Gebriel Reservoir, 400m$^3$ Red Cross reservoir and 350m$^3$ kebro school Reservoir.

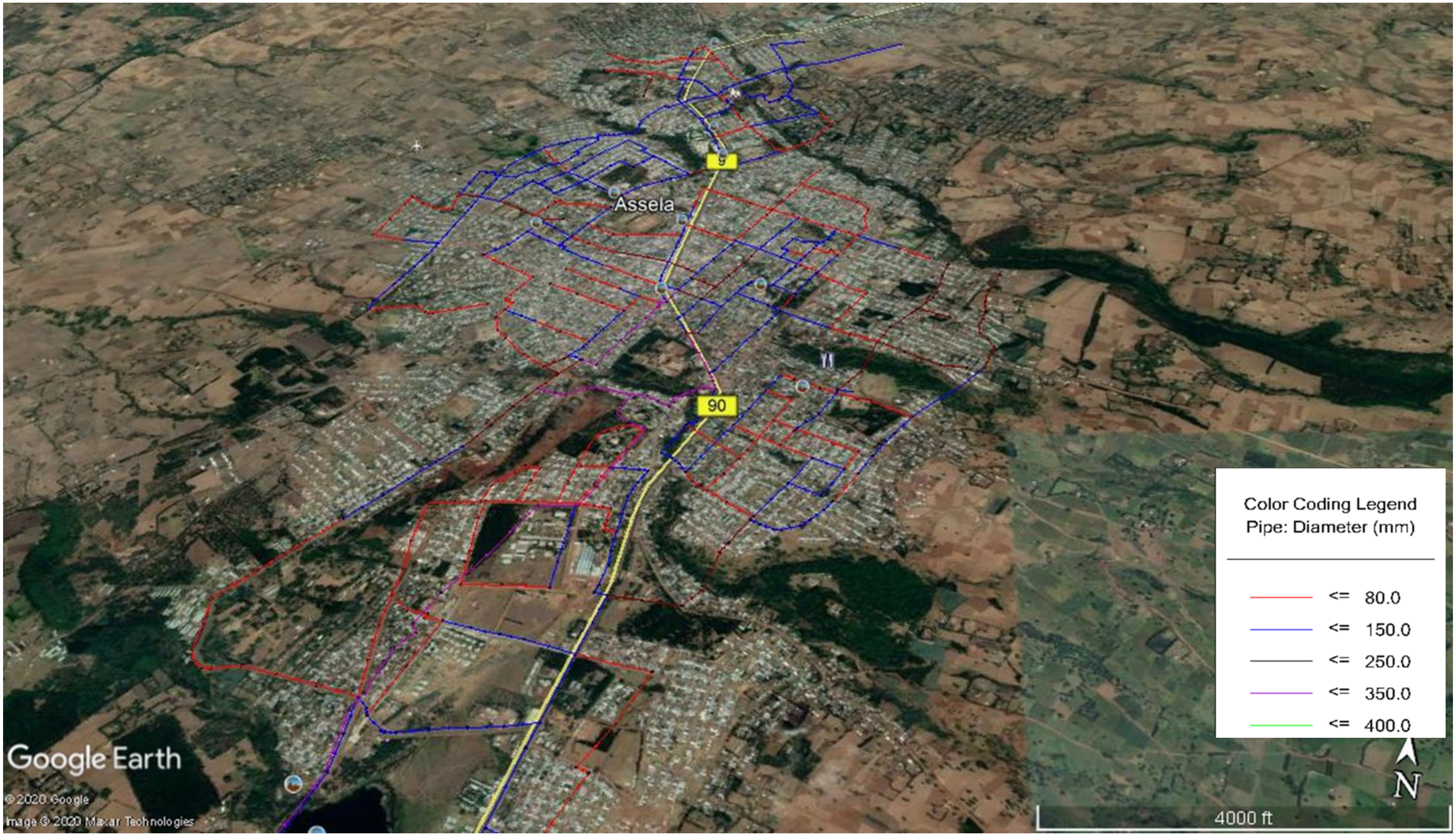


Figure 2: Layout of the Existing water system of Asella town.

Table 4: Length of pipe and their coverage used for modelling

| Diameter (mm) | Material |  | Length (m) | Coverage (%) |
|---|---|---|---|---|
|  | DCI | PVC |  |  |
| 50 | 788 | 11048 | 11836 | 12.075 |
| 80 | 5171 | 6479 | 11650 | 11.885 |
| 100 | 6281 | 10119 | 16400 | 16.731 |
| 150 | 8505 | 6939 | 15444 | 15.756 |
| 200 | 1700 | 3357 | 5057 | 5.159 |
| 250 | 919 | 813 | 1732 | 1.767 |
| 300 | 1080 | - | 1080 | 1.102 |
| 350 | 28711 | - | 28711 | 29.291 |
| 400 | 6111 | - | 6111 | 6.234 |
| Total | 59266 | 38755 | 98021 |  |

Source : (OWMEB, 2016)

As described in table 4 above, the total length of pipes represented in the model, materials were DCI covers 60.46% and polyvinyl chloride (PVC) covers 39.54 %. The model contain different diameter among them 350mm, 100mm and 150mm pipes are used in high percentage compared to other diameter of pipe represented in the model

Table 5: Summary of water distribution network elements

| System components | Number of element represented |
|---|---|
| Junction | 650 |
| Pipes | 724 |
| Tank | 4 |
| Pump | 2 |
| Reservoir(balancing chamber ) | 1 |
| Treatment plant | 1 |
| Reservoir(Clear water tank at treatment plant) | 1 |
| Intake | 2 |
| Flow control valve | 6 |

Source : (OWMEB, 2016)

### 3.4.3 Hydraulic Modeling of water supply Distribution Network using Bentley Water GEMS V8i

Analysis of water distribution network provides the basis for the design of new systems, the extensions, and control of existing systems. 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. 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. WaterGEMSV8i could show pressure, demand, and hydraulic grade in different nodes as well as flows, velocities, head-loss gradient and head-loss in different pipes throughout the distribution system.

#### *3.4.3.1 Assigning base water demands to each node*

To assign base demand to each supply node, it is necessary to estimate base demand of each node in the distribution network by following the steps below:

Step One: Population Forecasting

In order to avoid over or under estimation of the future population 2007 CSA population projection using 1994 medium variant growth rate set for Oromia region was used. Exponential population forecasting method is used to forecast the current Asella town population. This method is useful for projections on short term basis hence extrapolation over a five-year period makes it suitable. It is a hybrid of the geometric and arithmetic methods and corrects the anomalies of the methods (Mekuriaw, 2019).

$$\mathrm{P_n = p_0 e^{rn}} \quad \text{…………………………………………………………………… (Eq.3.4)}$$

Where: Pn=population at n decades or year, Po=initial population (from census), r=growth rate, n =decade or year, e=constant exponential value (2.718).

Table 6: urban population growth rate

| Description | Unit | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|---|
| Growth rate | % | | 4.00% | 3.80% | 3.50% | 3.30% | 3.00% |

Step Two: Identification of number of houses around each supply node

In ArcMAP, the ortho image of Asella town was opened and the town water supply distribution network constructed in Water GEMS by using model builder was exported into the AutoCAD DXF file and imported into ArcGIS was overlapped on it. Therefore, the number of each house was counted and assigned to the nearest supply node. An Excel sheet was created for demand allocation. The first column contained all the 650 demand nodes. The second and third column showed the longitude and latitude of demand nodes. The fourth column showed the number of houses assigned to that node as shown in Appendix A.

$$\text{Average people per house} = \frac{\text{Total curent population}}{\text{Total number of house}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq.3.5)}$$

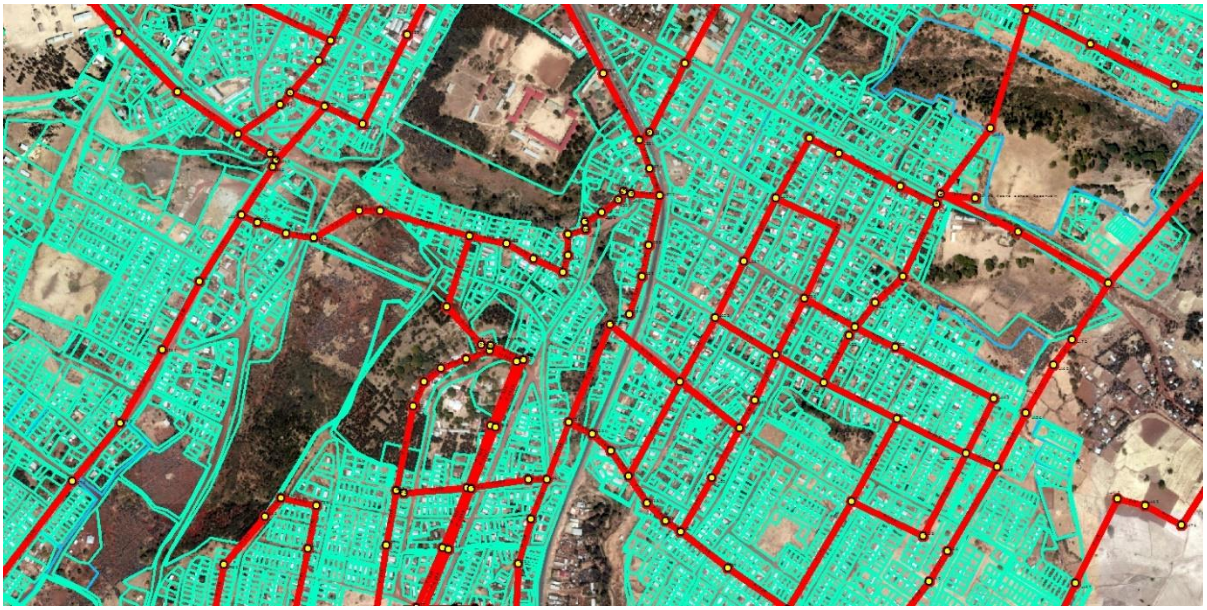


Figure 3: Distribution network overlapped on the map of the Asella town

Step Three: Determination number of peoples in per single-family residence each supply node

Currently, the population of the town is about 97118 peoples. The total number of houses identified was 20475, giving an average count of 4.74 people per house. To calculate the population served to each node in the fifth column the number of houses was converted to the number of people by multiplying by the above conversion factor.

$$\text{Number of people for supply} = (\text{Number of house assigned by that node} \ * \\ \text{average number of people in each house}). \ldots. \text{(Eq.3.6)}$$

Step Four: Determination of average day water demand of Asella Town

Average water demand of the town was calculated by multiplying the average per capital demand with the estimated number of populations as follow

$$\text{ADD} = \text{per capital water consumption} * \text{total population}$$

Step Five: Determination base water demand in each supply node

After the average daily water demand of the system was determined, base water demand for the particular supply node were calculated by using equation 3.7 and finally assigning into the node manually.

$$\text{Base demand for supply node} = \frac{\text{population served by node}}{\text{Total population}} * \text{ADD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq.3.7)}$$

Or

$$\text{Base demand for supply node} = (\text{Population served by node} * \text{per capital water consumption})$$

### 3.4.3.2 Assigning roughness coefficients to pipelines

Hazen-William roughness factors were used to incorporate frictional losses and the following roughness coefficients are suggested for existing pipes, depending on age and material and the remaining pipe sections are adjusted for their C-values accordingly:

Table 7: Hazen-Williams Roughness Coefficients

| Material | Hazen Williams Coefficient |
|---|---|
| Aluminum | 130 – 150 |
| Asbestos Cement | 120 – 150 |
| Asphalt-lined iron or steel | 140 |
| Brass | 130 |
| Cast Iron, cement lined | 140 |
| Cast Iron, coated | 110 – 140 |
| Cast Iron, new unlined | 130 |
| Cast Iron, old unlined | 40 – 120 |
| Cast Iron, uncoated | 100 – 140 |

| | |
|---|---|
| Cast Iron, 10 years old | 107 – 113 |
| Cast Iron, 20 years old | 89 – 100 |
| Cast Iron, 30 years old | 75 – 90 |
| Cast Iron, 40 years old | 64 – 83 |
| Cement lining | 140 |
| Concrete | 100 – 140 |
| Concrete, old | 100 – 110 |
| Copper | 130 – 140 |
| Corrugated Metal Pipe | 60 |
| Corrugated Steel | 60 |
| Deteriorated old pipes | 60 – 80 |
| Ductile Iron | 120 – 145 |
| Fiberglass | 150 |
| Galvanized Iron | 100 – 120 |
| Glass | 130 |
| Lead | 130 |
| Polyethylene | 140 |
| PVC, PE, GRP | 120 – 150 |
| Steel, new unlined | 120 |
| Steel, 15 years | 200 |
| Steel, riveted joints | 95 – 110 |
| Steel, welded joints | 100 – 140 |
| Steel, welded joints, lined | 110 – 140 |
| Steel, welded or steamless | 100 – 120 |
| Tin | 130 |
| Wood Stave | 110 |

Source:https://www.piping-designer.com/index.php/properties/fluid-mechanics/2500-hazen-williams-coefficient

#### *3.4.3.3 Assigning demand patterns*

The average demand is subjected to hourly variations, which mean the demand pattern based on the differences in living standards, industrial water use, Commercial, Public, Firefighting etc. Since the type of Simulation used for this modeling is the Extended Period Simulation to evaluate system performance over time. For such type of simulation, the demand patterns of the town for each node should be identified and the demand variation of each pattern has to be clearly set as well. The major demand patterns of the town are: Residential, Commercial, Public and Industrial are the major ones.

## 3.5 Model Calibration and Validation

For model calibration and validation effort data were collected from field selected sample locations. Once a water distribution model has been developed, it must be calibrated so that it accurately represents the actual working real life water distribution network under a variety of condition. This involves making minor adjustment to the input data then the model accurately simulated the pressure rate in the system. Pressures are measured throughout the water distribution system using pressure gage instrument to use the data for model calibration.

### 3.5.1 Calibration Statistics

There are many ways to judge on the performance of model calibration, the calibration statistics used in this study was by calculating the squared relative difference between observed and simulated pressure for each test. The results and the observation data were entered to an excel sheet and the value of squared error was calculated for every test then the mean square error and standard deviation calculated from Excel sheet.

### 3.5.2 Pressure measurement

Pressures are measured throughout the water distribution system to monitor the level of service and to collect data for use in model calibration. Pressure readings are commonly taken at fire hydrants also at hose bibs, and home faucets (Bentley, 2008). In this study the pressure measurements were taken at a direct connection to the water main nodes and nearer to the supply main nodes at homes faucet.

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 is 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 at a direct connection to the water main nodes and nearer to the supply main nodes at homes faucet as shown in figure 4 below.

Figure 4: Pressure measurement at different location

### 3.5.3 Network Simulation

Extended period simulations (EPS) are used to evaluate system performance over time. This type of analysis allows the user to model tanks filling and draining, regulating valves opening and closing, and pressures and flow rates changing throughout the system in response to varying demand conditions and automatic control strategies formulated by the modeler

### 3.5.4 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.

#### *3.5.4.1 Pressure*

The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network. The minimum pressure should maintain to ensure that consumers' demand provided at all times. The maximum pressure also contains limitation of leakage and lead to water losses in distribution system. The operating pressure in the distribution network is given in table 8 below.

Table 8: The allowable operating pressures in the distribution network from (MoWR,2006).

| Conditions | Normal conditions | Exceptional conditions |
|---|---|---|
| Minimum | 15m water head | 10 m water head |
| Maximum | 60m water head | 70m water head |

### 3.5.4.2 Flow Rate

It is the quantity of water passes within a certain time through 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 estimated. Low velocities affect water consumption and severe to diseases problem.

$$v = \frac{4Q}{\pi D2} \quad \text{…………………………………………………………………………….} \quad \text{(Eq.3.8)}$$

Where, D= diameter of the pipe (m); Q= discharge (m3/se) and V= velocity (m/sec). 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 presented in table 9 below.

Table 9: Pipe velocity range given by different organization.

| Distribution type | MoWR (2006) | (Worldbank, 2012) | (OWDSE, 2010) |
|---|---|---|---|
| Maximum velocity main line | 2 m/s | 3 m/s | 2.5 |
| Maximum velocity in distribution | 2 | 1.5 m/s | 0.8 -2.1 |
| Minimum velocity in distribution | 0.6 m/s | 0.4 m/s | 0.5 |

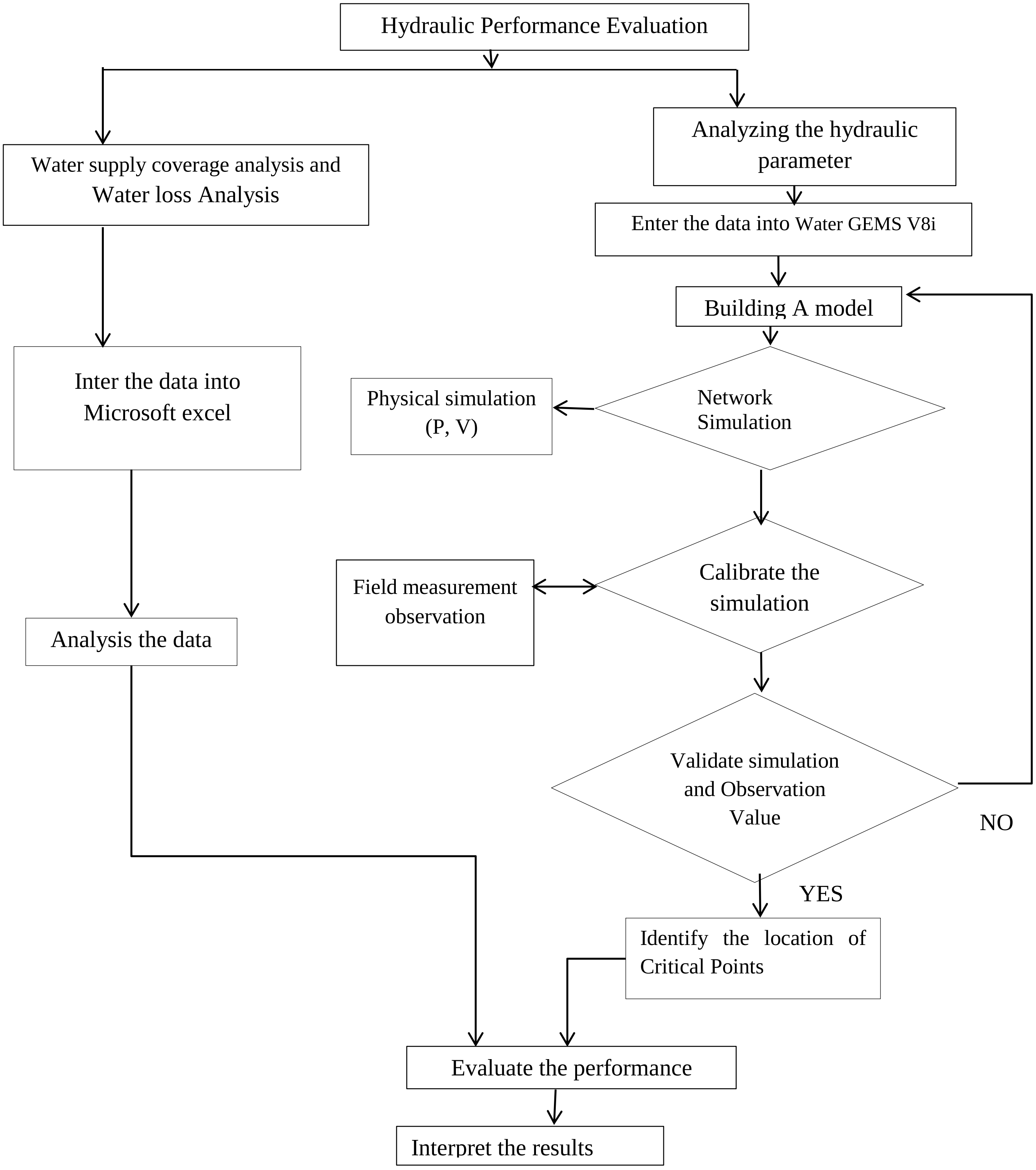


Figure 5: Schematic diagram of research methodology

# 4 RESULT AND DISCUSSION

## 4.1 Water Supply Coverage Analysis and Water losses analysis

### 4.1.1 Water Supply Coverage Analysis

#### *4.1.1.1 Average per capita demand coverage*

The water supply coverage of the town is evaluated based on the average per capita consumption. The average water consumption per capita was derived from the town's annual consumption, which was aggregated from the individual water meter and the public tap. Thus, the annual water consumption data is converted to average daily per capita consumption using the population data of the town. Average daily per capita water consumption of the town in 2020 G.C was calculated from the total annual recorded consumption of the town by using equation 3.1.

$$\text{Per capita consumption (lcd)} = \frac{(1{,}251{,}806.00\text{m3} * 1000\text{l/m3})}{(97118 * 365\text{ day})} = 35.31\ lcd$$

The average domestic water supply coverage of the town is 35.31 l/c/day. This average per capita consumption is very low as compared to the value set by MoWIE (2019) for second Growth and Transformation Plan (GTP-2) which 60 l/c/d for category-3 towns/cities within a distance of 250 m.

The annual water demand for the year 2020 is 13427.49 $m^3$/day * 365 day which is 4901033.85$m^3$ and the annual water production of the town in 2020 G.C is 2070653$m^3$ as described in annex-A. So the water supply coverage is the ratio of annual water production and annual water demand.

$$\text{Water Supply Coverage}(\%) = \frac{2070653\text{m3}}{4901033.85\text{m3}} * 100 = 42.249\%$$

### 4.1.2 Water losses analysis

Basically ahead of assigning nodal water demand, it is very common to quantify water loss in the water distribution system. The difference between production and water consumption is quantified as total water loss. Water loss in the system is frequently due to either leakage in the system or apparent loss which includes; meter inaccuracy, illegal use of water by unauthorized person etc.

The total annual water produced and distributed to the distribution system and the water billed that was aggregated from the individual customer meter readings were used to quantify the total water loss for the town. Water loss is usually expressed in terms of percentage (UFW), loss per kilometer length of main pipes and loss per properties or number of connections. The total water loss has been evaluated based on the three measurement approaches as explained here under.

#### *4.1.2.1 Total Water Loss Expressed as Percentage (UFW)*

The total annual water produced and distributed to the system within the specified year of 2020 G.C is 2,070,653 cubic meters and the annual total water loss is 818,847 cubic meter that accounts to 39.55 % of the total water production. As depicted in figure 7 below the total annual water loss of the water supply system is 28.39% in 2016, 31.83% in 2017, 39.28% in 2018, 37.16% in 2019 and 39.55% in 2020 G.C. The average amount of water, which actually reached the consumers in Asella town accounts for only 64.76% of the total water produced. According to Mckenzie *et al* (2006), the system efficiency is good (acceptable) if above 75% of water produced reaches the consumer. Thus, Asella town water supply system is not good. As it shown from figure 6 below, non-revenue water from the system is vary from year to year due to the aging of pipe that leads to leakage, pipe bursting, installation (extension of network in new area) and illegal connection

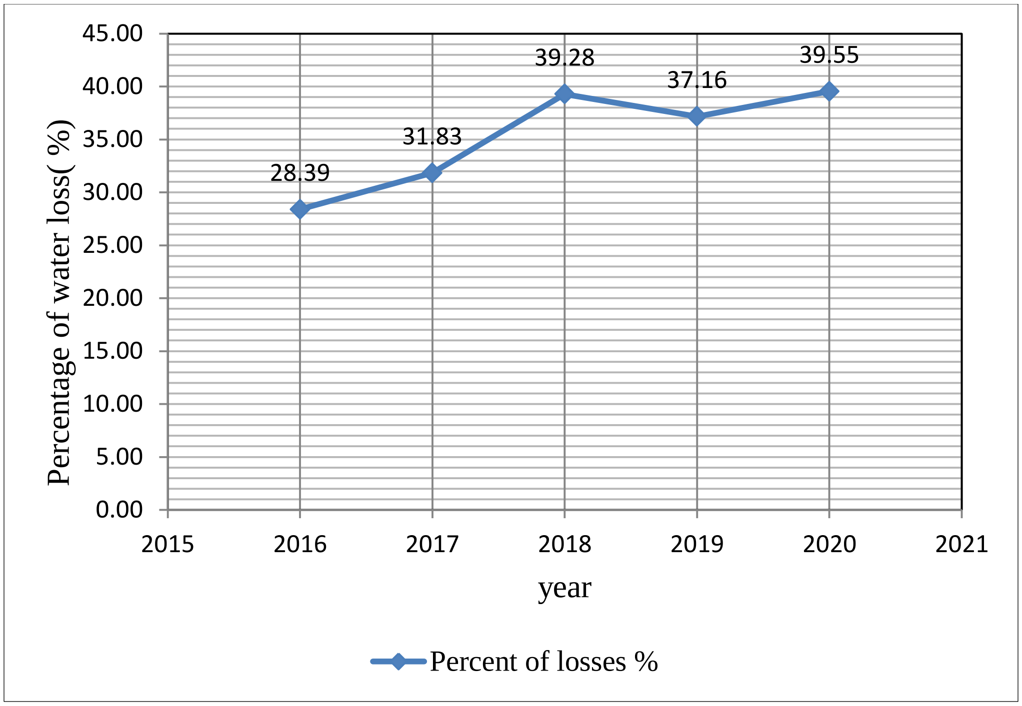


Figure 6: Annual water losses of the town

Therefore, AWSSE should plan to work on identification of causes for unaccounted for water and take appropriate mitigation measures to minimize the problem and thereby save water for the domestic and other municipality purposes.

#### *4.1.2.2 Water Loss Expressed as per Number of Connection*

Water loss expressed as a percentage is an appropriate means to show the extent of the loss within a given environment, but it is not a good indicator for comparing the losses from one area to another. According to some literatures, comparison of water loss between different areas is recommended to be done using the water loss per service connection per day. Taking the total number of connection in the town as 18,200 the water loss per connection for the similar duration was derived as,

Water loss = 818847 x1000÷ (18200×365) = 123.26 liter/connection /day. This figure shows as litters per service connection per day increase water losses also increases.

#### *4.1.2.3 Water Loss Expressed as per Length of Pipes*

Water loss expressed as per kilometer length of main pipes is also used as indicator to compare water loss. This indicator is usually recommended for non- densely populated areas. The total length of pipes of greater or equal to 50mm diameter have been used to evaluate total water loss of the entire town is 98.021km . Using total pipe length of the entire town, the water loss per kilometer length of main pipes was derived to be 818847 ÷ (98.021 km×365days) = 22.8871 $m^3$/km/day**.** This figure shows that as length of the pipe increases the amount of water losses per day increases.

#### *4.1.2.4 Possible reasons of high water loss*

Regarding the system efficiency of the existing distribution system, the data obtained from the water supply service enterprise bill data has been used to estimate the water loss within the system. As depicted in figure 7 above the losses of water within the system don't have uniform trend of increase or decrease instead it undulate from year to year.

Water loss from transmission caused by over flow from tankers due to absence or malfunctions of automatic flow control valve or float valves, metered but unbilled water like the water point connected to pressure line. Leakage from corroded, old defective and broken pipes, leakage and overflow at service reservoirs, water loss caused by metering inaccuracies, Unbilled metered consumption, unbilled unmetered consumption or illegal connection, unbilled metered consumption, leakage on service connections up to point of customer metering, leakage caused by connecting distribution pipes lines and leakage due poor workmanship and using of nonstandard pipes and fittings.

## 4.2 Model Calibration and Validation

### 4.2.1 Calibration of hydraulic network model

Calibration is the process of comparing the model results to field observations and, if necessary, adjusting the data describing the system until model-predicted performance reasonably agrees with measured system performance over a wide range of operating conditions. The hydraulic simulation software simply solves the equations of continuity and energy using the input data; thus, the quality of the input data affects the quality of the results. The accuracy of a hydraulic model depends on how well it has been calibrated, so a calibration analysis should always be performed before a model is used for decision-making purposes. Ten data sets were selected from field observation and from simulated results for calibrating the model.

#### *4.2.1.1 Model Performance Evaluation criteria*

There are many ways to judge on the performance of model calibration. The evaluation was made by calculating the squared relative difference between observed and simulated pressure for each test. The evaluation criteria used was statically method using correlation coefficient (R2).

$$R^2 = \frac{\text{sum}(X-\text{Xmean})(Y-\text{Ymean})}{\text{SQRT}((\text{sum}(X-\text{Xmean})^2 * \text{sum}(Y-\text{Ymean})^2)}$$

Where $R^2$ is Correlation Coefficient, X and Y are measured and simulated values, Xmean and Ymean are average value of measured and simulated data respectively.

#### *4.2.1.2 Pressure Calibration*

The degree of accuracy varies depending on the size of the system and the amount of field data and testing available to the modeler. Bentley (2008), states that the average difference of ±1.5m to a maximum of ± 5.0m for a good data set and ± 3.0 to ± 10m for a bad data set would be a reasonable target.

Table 10: Data Arrangement for pressure Calibration and Time series with pressure networks

| S.NO | Sample Location pints | Location | | | Observed Pressure(m) | Computed Pressure | Difference pressure error | Measured Time | Scenario |
|---|---|---|---|---|---|---|---|---|---|
| | | x(m) | y(m) | Elevation | | | | | |
| 1 | J-199 | 514382.24 | 875689.38 | 2542.42 | 10 | 15.65 | 5.65 | 6:30 | Base scenario |
| 2 | J-208 | 513759.03 | 879858.54 | 2362.24 | 1 | 0.26 | -0.74 | 7:15 | |
| 3 | J-171 | 513621.56 | 875785.56 | 2521.1 | 23 | 26.67 | 3.67 | 7:45 | |
| 4 | J-388 | 514393.67 | 878118.78 | 2451.26 | 16 | 18.42 | 2.42 | 8:30 | |
| 5 | J-75 | 515792.26 | 879088.09 | 2462.73 | 12 | 9.01 | -2.99 | 9:00 | |
| 6 | J-233 | 513925.7 | 879367.74 | 2371.79 | 64 | 63.12 | -0.88 | 10:00 | |
| 7 | J-107 | 514094.97 | 877521.32 | 2488.24 | 40 | 45.08 | 5.08 | 10:45 | |
| 8 | J-140 | 516035.76 | 878974.14 | 2485.12 | 35 | 37.7 | 2.7 | 11:30 | |
| 9 | J-169 | 515469.79 | 877807.04 | 2514.32 | 8 | 9.27 | 1.27 | 12:00 | |
| 10 | J-582 | 514749.45 | 877787.97 | 2458 | 9.5 | 11.01 | 1.51 | 1:00 | |
| | | | | | | Average Error | 1.769 | | |

As shown in table 12 above, computed values are within an average error of 1.769m pressure simulated to observed values. Hence, the model is acceptable calibrated which is satisfied the setting pressure calibration and validation criteria under average level (average +1.5m to the maximum +5m). The agreement between the observed field data and the model result graphically sketched to show the overall relationship in between the two data sets as follow.

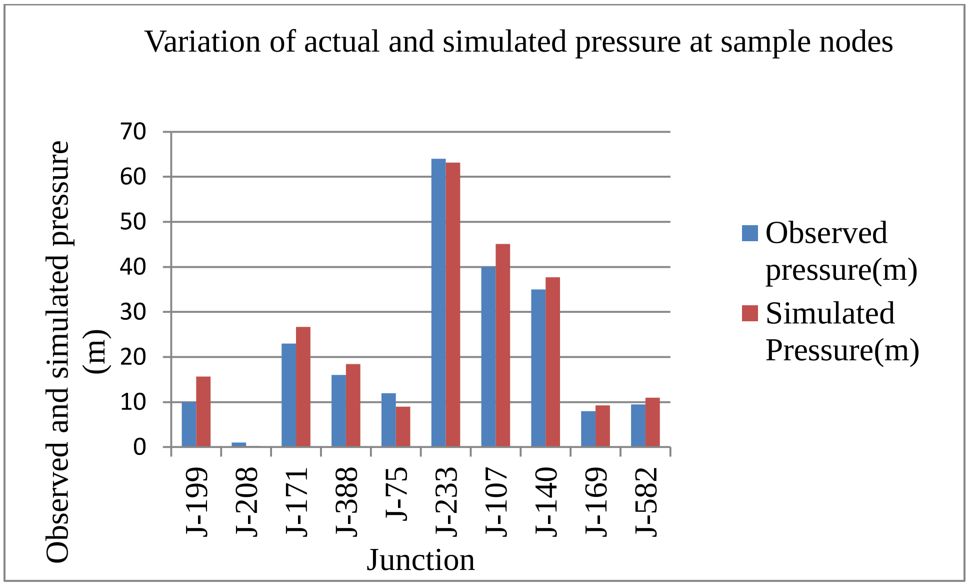


Figure 7: Actual and simulated pressure at samples node.

Pressures were measured in the field in order to compare with the results of the distribution system. Figure 8 below is a comparison plot of observed pressures versus calculated pressures at various distribution lines and taps throughout the system.

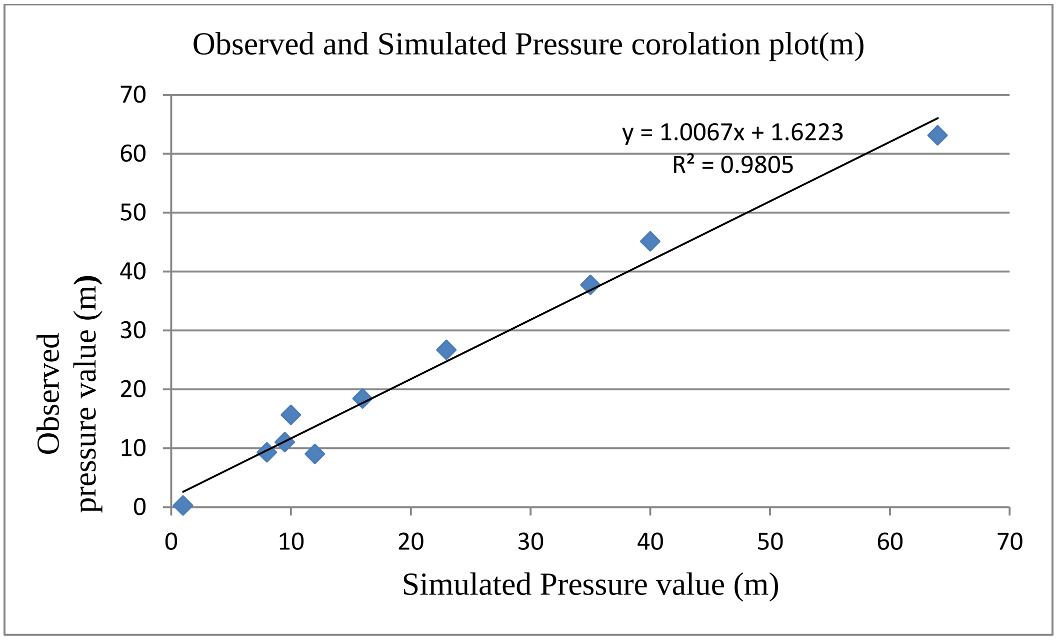


Figure 8: Correlation between observed and simulated pressure parameters

The diagonal line on the plot represents the line of perfect correlation in figure 8 above. Ideally all the points should align themselves on this line; meaning that all observed pressures is equal to the computed pressures, giving a correlation coefficient of 1 that is the best correlation between observed and simulated. The linear correlation coefficient ($R^2$) of observed versus computed pressures is at 0.9805. The coefficient of determination (R2) value was 98.05%, it indicates that observed and simulated relation is strongly as values tend to 1(the computed pressures are within the acceptable limit).

### 4.2.2 Model Validation

Model validation is the steps that follows calibration and uses an independent field data set to verify that the model is well calibrated. In the validation step, the calibrated model is run under conditions differing from those used for calibration and the results compared to field data. The model result is closely approximate the field results (visually) for an appropriate time period and the calibrated model is considered as validated.

## 4.3 Model Analysis

The system conditions have been computed over twenty-four hours with a specified time increment of one hour and starting model run time at 12:00 PM. The software simulates non-steady-State hydraulic calculation based on mass and energy conservation principle. The model is simulated for every one-hour time setup in the twenty-four hour duration. However, for the analysis the peak and minimum hours demand is simulated to identify the current problems of the system and to locate the critical points in existing water supply distribution network.

### 4.3.1 Hydraulic parameter in existing water supply distribution network

#### *4.3.1.1 Pressure*

The Ethiopian guideline criteria for the minimum and maximum operating pressure value in the distribution network are 15 m and 60m at normal condition respectively to efficiently make water available to each demand category and as to reduce leakage as well as pipe breakage across the system. The pressure is computed using Hazen-William approach.

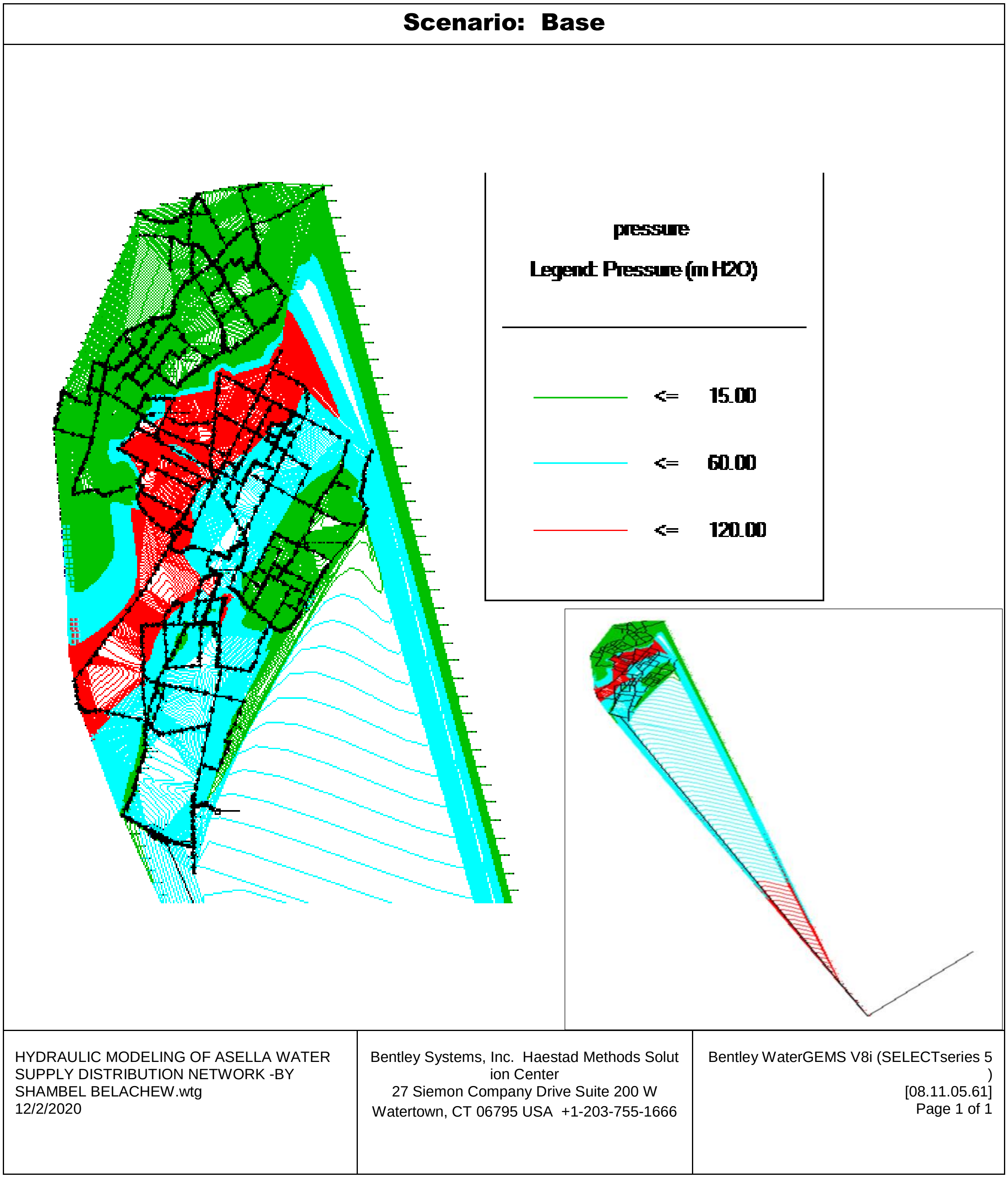
The extended-period simulation was chosen for this analysis because extended period simulation indicates the performance of the distribution system better than steady state simulation during high consumption or at stress condition. In this study, the model run from the input of existing data a total node of 650 was reported from the project inventory dialog box. Simulation of existing water supply distribution condition at peak hour demands as shown below in both tabular and figure and the results for pressure at peak flow is summarized in table 11 and figure 9 below and detailed in appendix C.

The minimum pressure adopted for this study is 15m of water head. As depicted in Table 11 below about 306 out of 650 Nodes are below the minimum adopted system pressure. This indicates that the pressure within the distribution system is 47.08% of nodes are below the minimum desirable pressures during peak hour demand and these nodes are not capable of supplying the necessary demand to consumers and 20.00% of nodes are exceeded to maximum allowable pressures of 60m at normal condition as described in table 5 under the methodology part. While 32.92% of nodes are within the permissible pressure ranges of minimum 15m and maximum 60m pressure head. At this peak hour level the water consumption demand expected to more over all the hour demands.

There are some reasons that are why the negative pressure is occurred in the water supply distribution system is as result of the following: elevations difference, high demands, pipes of inadequate capacity (too small diameter), rough pipes (e.g. corroding iron pipes or pipes with a build-up of sediment), and equipment failures (e.g. pumps and valves).

The low pressure nodes are normally those nodes which are located relatively at high elevations and far from the supply points. Low pressure can cause reduction of quantities of water supplied to the consumer and entry of a contaminant or self-deterioration of water quality within the network itself a severe damage to public health.

As described in figure 9 below the area highlighted by green color is indicate lower pressure (negative pressure) below 15m of water head, the area highlighted by aqua color is indicate permissible pressure range between15m to 60m water head and the area highlighted by red color are indicate pressure above maximum allowable operating pressures 60m of water head at normal condition.



**Scenario: Base**

| | | |
|---|---|---|
| HYDRAULIC MODELING OF ASELLA WATER SUPPLY DISTRIBUTION NETWORK -BY SHAMBEL BELACHEW.wtg<br>12/2/2020 | Bentley Systems, Inc. Haestad Methods Solution Center<br>27 Siemon Company Drive Suite 200 W<br>Watertown, CT 06795 USA +1-203-755-1666 | Bentley WaterGEMS V8i (SELECTseries 5)<br>[08.11.05.61]<br>Page 1 of 1 |

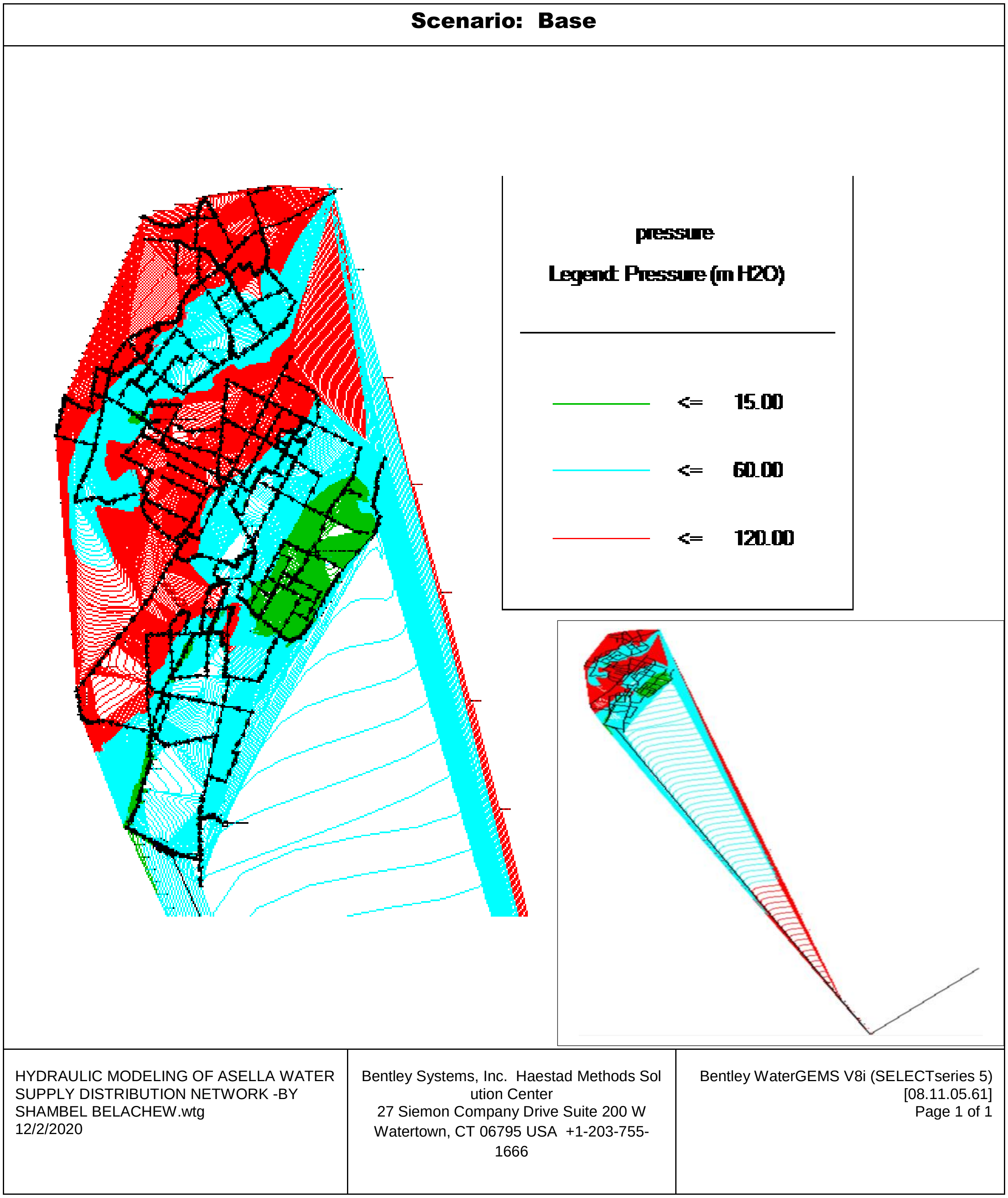
Figure 9: Pressure contour map of nodes at maximum consumption hours.

Table 11: Distribution of pressure at minimum and maximum consumption hours

| Pressure(mH2O) | pressure at minimum consumption hours | | pressure at maximum consumption hours | |
|---|---|---|---|---|
| | Node number | Percentage (%) | Node number | Percentage (%) |
| <10 | 51 | 7.85 | 290 | 44.62 |
| 10-15 | 14 | 2.15 | 16 | 2.46 |
| 15-20 | 32 | 4.92 | 23 | 3.54 |
| 21-30 | 51 | 7.85 | 36 | 5.54 |
| 31-40 | 67 | 10.31 | 52 | 8.00 |
| 41-50 | 63 | 9.69 | 49 | 7.54 |
| 51-60 | 85 | 13.08 | 54 | 8.31 |
| 61-70 | 83 | 12.77 | 52 | 8.00 |
| >70 | 204 | 31.38 | 78 | 12.00 |
| | 650 | 100.00 | 650 | 100.00 |

During low flow typically at mid-night distribution system of case study is marked by excessive pressure. As shown in table 11 above, Figure 10 below and detailed in appendix D, 10% and 44.15% of nodes below minimum and exceed maximum allowable operating pressures in the distribution network respectively. Minimum pressure is also observed during low consumption period. Only 45.85% of nodes are received water of optimum pressure at low consumption hour. As compared to distribution of pressure at maximum consumption hour table 11 above, shows only 32.92% nodes are with permissible pressure due to excessive demand.

As described in figure 10 below the area highlighted by green color is indicate lower pressure (negative pressure) below 15m of water head, the area highlighted by aqua color is indicate permissible pressure range between 15m to 60m of water head and the area highlighted by red color are indicate pressure above maximum allowable operating pressures 60m of water head at normal condition.



**Scenario: Base**

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12/2/2020

Bentley Systems, Inc. Haestad Methods Solution Center
27 Siemon Company Drive Suite 200 W
Watertown, CT 06795 USA +1-203-755-1666

Bentley WaterGEMS V8i (SELECTseries 5)
[08.11.05.61]
Page 1 of 1

Figure 10: Pressure contour map of nodes at maximum consumption hours.

According to this study output for Asella town, pressure zones (for elevated area, lower area and commercial or institutional area) may be better to see for modification. Because of during intermit supply pressure become above simulated pressure head. This also affects the hydraulic performance of the network.

Households located on higher elevations and close to reservoir site have get water at low water pressure. Variations of pressure during day and night can create operational problems, resulting in increased leakage and malfunctioning of water appliances. Reducing the pressure fluctuations in the system is therefore required (Ermias, 2014). The effect of distance and elevation in pressure distribution of selected nodes is given Figure 11 below.

Figure 11 below shows that, effects of distance and elevation in pressure distribution for selected junctions. The first (junction 199) and the last (junction 193) have an elevation and pressure head of 2542.42m a.s.l with 15.65m pressure and 2534.93m with 10.39m pressure respectively. When elevation decrease from junction 199 to a lowest point, pressure increases to that point and after lowest point (at junction 142) elevation starts to increase and pressure starts to decrease and continue up to the last junction. At junction 176 elevation starts to drops but pressure suddenly increase.

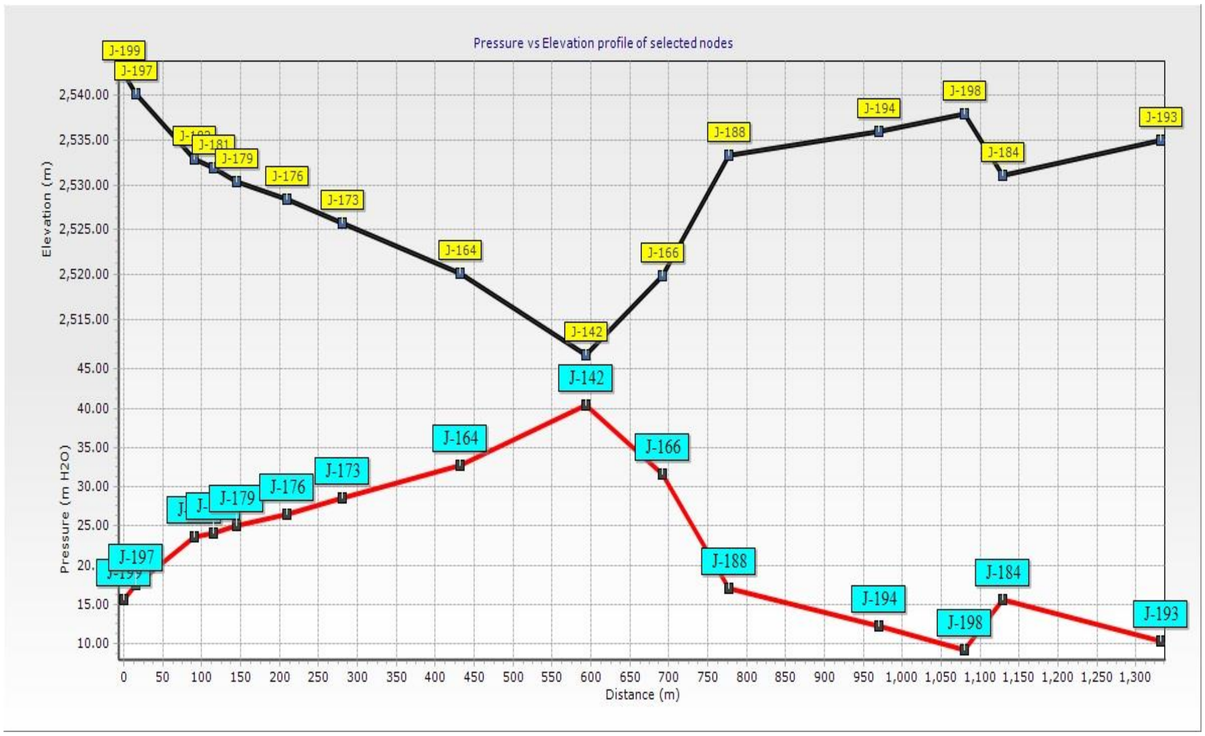


Figure 11: Profiles of pressure vs Elevation of selected nodes showing distance from junction 199 to the farthest point

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 and leakage rate are expected to be high because at this time no water flow occurred at the distribution.

#### *4.3.1.2 Velocity*

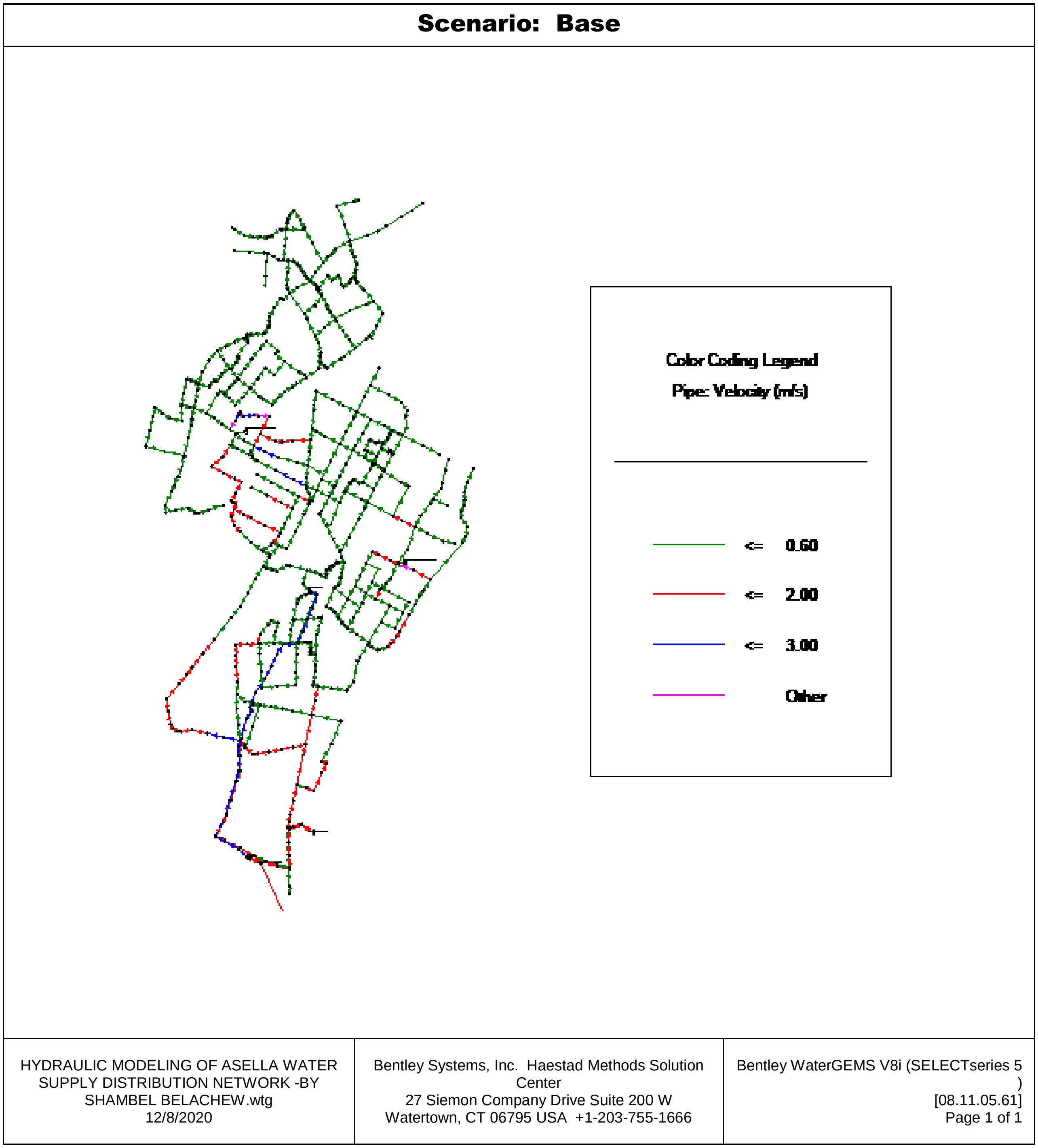
Velocity of water flow in a pipe is one of the important parameters in hydraulic modeling performance evaluation of the efficiency of water supply distribution and transmission line. Velocity distribution is also varying with demand pattern changes. Water velocity should maintain at less than 2m/sec, in distribution system and not more than 2.5 m/s in transmission system. A minimum velocity of 0.6 m/sec had taken, but for looped systems, there would be pipelines with section of zero velocity (MoWR, 2006;OWWDSE,2010). At the peak hour demand the values are different as compare to minimum consumption hour. The water supply system network velocity during peak hour demand is summarized in the table 15 below

Table 12: Velocity Distribution in Pipe at peak hour demand

| Velocity range (m/s) | Count | Count (%) | Effect |
|---|---:|---:|---|
| ≤0.6 | 576 | 79.56 | Sedimentation problem |
| 0.6-2 | 102 | 14.09 | Normal |
| ≥2 | 46 | 6.35 | Erosion and high head loss occurred |

As depicted in Table 15 above, during the peak hour demand situations about 6.35% of pipes are failed to satisfy the permissible velocity or maximum velocity in distribution and transmission line (>2 m/s), in addition to that, 79.56% of pipes also below the minimum velocity in a distribution lines (<0.6 m/s). While, only 14.09% of pipes are in the permissible velocity ranges. Velocity has also a great impact on water quality as turbidity and the like.

Low velocities are undesirable because they lead to low pipe flows, since discharge is a function of velocity. Also low velocities are undesirable for reasons of hygiene and sedimentation problem. In opposite way, high velocity, not more than 2.0 m/s and 2.5 m/s in distribution system and transmission system respectively to prevent erosion and high head losses.



**Scenario: Base**

| | | |
|---|---|---|
| HYDRAULIC MODELING OF ASELLA WATER SUPPLY DISTRIBUTION NETWORK -BY SHAMBEL BELACHEW.wtg<br>12/8/2020 | Bentley Systems, Inc. Haestad Methods Solution Center<br>27 Siemon Company Drive Suite 200 W<br>Watertown, CT 06795 USA +1-203-755-1666 | Bentley WaterGEMS V8i (SELECTseries 5 )<br>[08.11.05.61]<br>Page 1 of 1 |

Figure 12: Velocity Distribution in Pipe at peak hour demand

In general the study area of water distribution system has some problems with respect to hydraulic network modeling. These are low pressure, high pressure, high velocity, and low velocity due to undersized and oversized service pipe diameter and inadequate water supply. Low pressure problem is due to high elevation and undersized pipes diameter and high pressures are usually caused by low elevation and oversized service pipe diameter

#### *4.3.1.2.1 Possible reasons of low velocity in pipe system*

Since discharge is a function of velocity and velocity is a function of pipe size, the results of discharge and velocity is used for the judgment for solving the distribution network problems related to pipe size. Inadequate water supply, oversized service pipe diameter and topography is the major problem which causes low velocity of water in the pipe system. Topography of Asella town is characterized as rugged and inclined. At low elevation and oversized service pipe diameter, the velocity of water is low and the pressure is high.

#### *4.3.1.2.2 Head losses in the pipes*

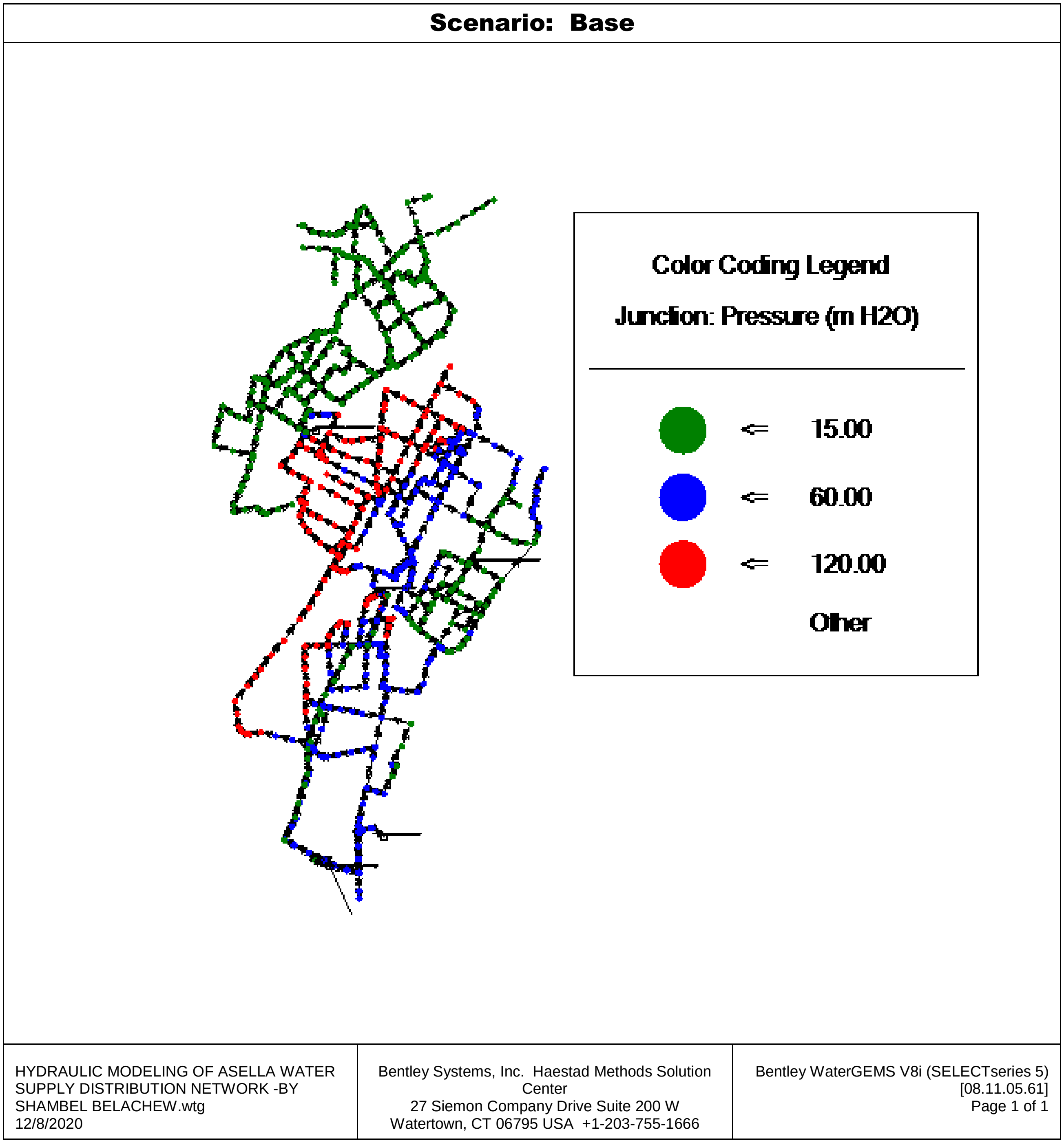
The modeled head losses enable to judge whether booster stations are needed or not to boost the water pressure and add energy to let the flow continue. The model simulated shows that head loss in p-269, p-270, p-271, p-272, p-273, p-274, p-275, p-279, p-280, p-285, p-286, p-288, p-488, p-489, p-498, p-499, p-500, p-501, p-502, p-503, p-506, p-507, p-508, p-509, p-510, p-511, p-512, p-513, p-514, p-515, p-516, p-660, p-661, p-662, p-663, p-664, p-665, p-666, p-667, p-668, p-669, p-675, p690, p-723, p-724 are very high as depicted in AppendixE.

Generally, undersized pipes would lead to increased head losses due to increased friction. However, over sizing pipes beyond reasonable limits would increase the contracting cost. As the length of the network increases and the number of pipes, valves, fittings and other obstructions in the system increase, both major and minor losses increases.

### *4.3.1.3 Identification of the location of Critical Points*

If a pipe is too small, it may become a problem only during high flow conditions; the best time for diagnosing problems is the model simulation during peak hour flow. A color coding is specified for several ranges of pressure heads at the junctions and was help to understand the difference in pressure range at various junctions.

There are total 650 nodes in the model, out of them 306 nodes receive water with less than to 15m pressure head of water which is inadequate and 52 nodes receive water with greater than to 60m pressure head of water and those nodes denotes as critical points. It is observed that the pipe capacity is insufficient and oversized diameter to deliver water with the required pressure. To maintain the pressure head at those nodes it is better to add parallel pipes in the distribution network. Use pressure sustaining valves to control the occurrences of minimum pressures and pressure reducing valve to control occurrences of maximum pressures for parts of high elevation network.



**Scenario: Base**

Color Coding Legend

Junction: Pressure (m H2O)

🟢 <= 15.00

🔵 <= 60.00

🔴 <= 120.00

Other

| | | |
|---|---|---|
| HYDRAULIC MODELING OF ASELLA WATER SUPPLY DISTRIBUTION NETWORK -BY SHAMBEL BELACHEW.wtg<br>12/8/2020 | Bentley Systems, Inc. Haestad Methods Solution Center<br>27 Siemon Company Drive Suite 200 W<br>Watertown, CT 06795 USA +1-203-755-1666 | Bentley WaterGEMS V8i (SELECTseries 5)<br>[08.11.05.61]<br>Page 1 of 1 |

Figure 13: Identification of critical points in the distribution system

In the figure 13 above the green color nodes have pressure head below 15m of water head, red color nodes have pressure head above 60m of water head and they denotes as the critical points in the distribution network while the nodes in the blue have pressure head between 15m-60m of water head.

### 4.3.2 To cope-up the above problems

Asella town water supply and sewerage enterprise must redesign water distribution system at peak hour with maximum day demand. By examine what is going on the system as result of peak hour, solutions is given to the problems faced (pressures and velocities out of the design limit) within the network. Take a modification to the problems by creating new alternatives and scenario. At peak hour demand the velocities out of the design range are modified by resizing pipe diameters and pressures at junction of lower portion were high, reduction to the desired pressure has been made by using pressure reducer valves (PRVs) and pressures at junction of higher portion were low, uses pressure sustaining valves to control the occurrences of minimum pressures.

# 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

Asella town is suffering from the discontinuous supply of water in the distribution systems. Pressures in distribution system fail at maximum consumption hour and high during night time as consumption decreases. 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. Therefore this study is used to evaluate the hydraulic performance of water supply distribution system of Asella town by using Bentley water GEMS V8i. The total annual water loss of the water supply system is 28.39% in 2016, 31.83% in 2017, 39.28% in 2018, 37.16% in 2019 and 39.55% in 2020 G.C. The amount of water which actually reached the consumers in average from 2016 G.C to 2020 G.C is 64.76% of the total annual water production.

In extended period simulation of peak hour consumption, parts of the distribution system receive water with low pressure and under some circumstances risk of obtaining no water is observed because of the pressure in the distribution system is below permissible minimum requirement. 47.08% of the identified nodes have pressure below 15 m were negative pressure at peak time consumption and 20% of the nodes has pressure above 60 m. 32.92% of the areas have pressure within the recommended limit (15 to 60 m). For the parts of the system that are located far away from the sources, or have high elevation, it is clearly obvious that they are suffering from low-pressure values. At low pressure the water cannot reach at end taps and elevated areas.

The result of extended period simulation of low consumption time shows, 10% of the nodes have pressure below 15 m and 44.15% of the nodes have pressure above 60 m. Thus, only 45.85% of the areas have pressure within the recommended limit (15 to 60 m). The result of extend period simulation at maximum water consumption hours shows, 79.56% of the flow velocity of links were below minimum allowance velocity (0.6m/s). Nodes below minimum and exceed maximum allowable operating pressures in the distribution network represent the critical points. The town water supply distribution system service coverage was also evaluated using the water demand and water production having 42.249 % coverage for the year 2020G.C

## 5.2 Recommendations

From annual water production, annual water demand and from hydraulic network modeling simulation, water supply of the town is failed to meet current demand. Therefore, add new source and upgrade capacity of existing water distribution system needed to deliver adequate water. According to production and consumption data analysis, water loss was increased with time for the past five years. Therefore old component of distribution system should be replace with new component and farther study should be done on the studied area.

Pressure during hydraulic simulation in the distribution system found that high at low elevated area (above 60 m) when there was low demand. The higher the pressure exposed to breakage, leakage and burst of pipe during intermittent supply and excess water deliver at low demand. This increase water loss and lowered performance of water distribution system. Then to enhance the pressure divide the distribution network into different pressure zones for elevated, lower and commercial area or institutional area and to sustain the pressure head at those nodes it is better to add parallel pipes or increasing its diameter to deliver water with the required pressure.

In order to achieve (15- 60 m pressure), uses of pressure sustaining valves are recommended as to control the occurrences of minimum pressures. These valves start closing if the pressure falls below the present value as to guarantee allowable minimum pressure for isolated parts of area and also establishing boosting station is recommended. Pressure reducing valve devices which decrease pressure are recommended as solution to control occurrences of maximum pressures for parts of high elevation network.

Remote points of the distribution system are not getting enough amount of water so, proper arrangement of height of reservoir or pipe diameter is important to satisfy system service level. Hydraulic network simulation shown flow fails to achieve minimum allowances velocity (0.6 m/s) at peak hour demand. This exposed water age, sedimentation and hygiene problem. Due to this reason the Asella town water supply and sewerage enterprise must check water quality at the end of consumer taps.

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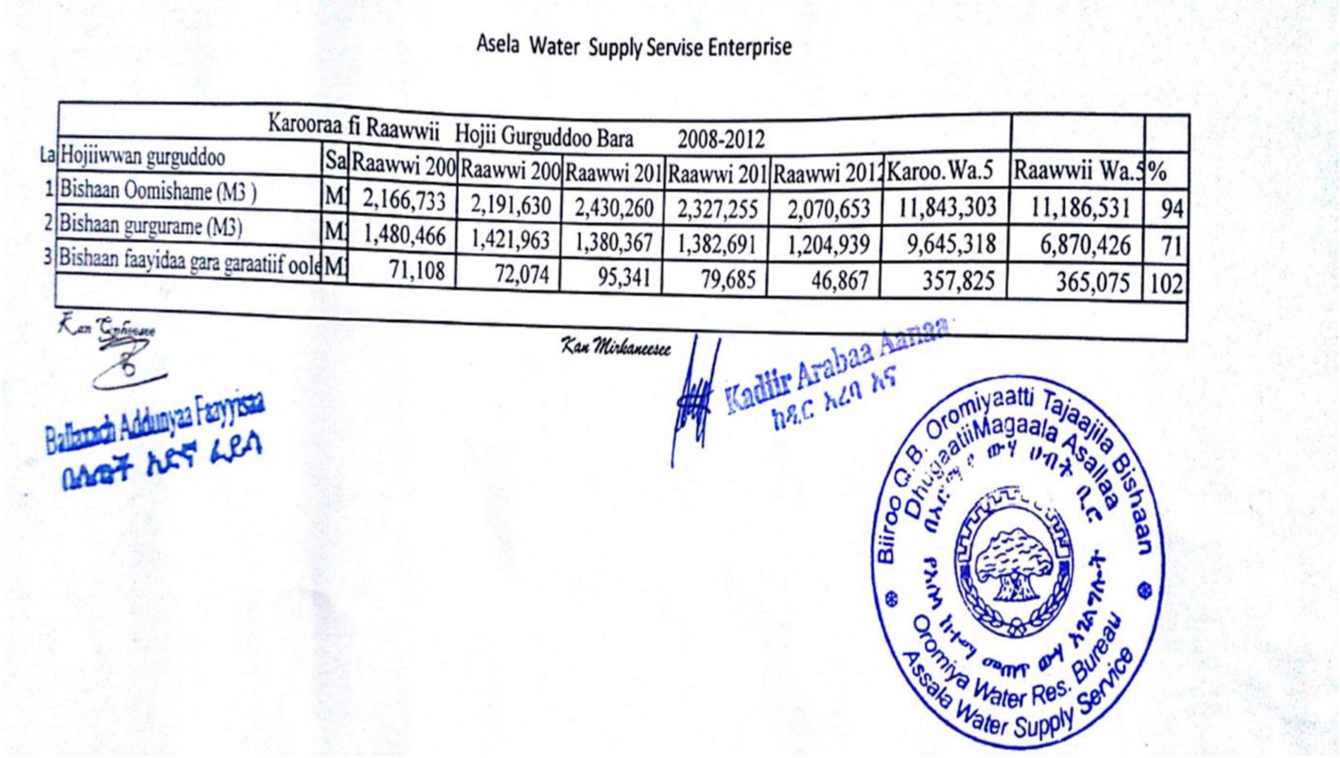
# APPENDICES

## Annex 1: Total volume of water production and consumption from (2016-2020 G.C)

| Description | Unit | year G.C | | | | |
|---|---|---|---|---|---|---|
| | | 2016 | 2017 | 2018 | 2019 | 2020 |
| Volume of Water Produced | m3 | 2,166,733.00 | 2,191,630.00 | 2,430,260.00 | 2,327,255.00 | 2,070,653.00 |
| Volume of Water Sold | m3 | 1,551,574.00 | 1,494,037.00 | 1,475,708.00 | 1,462,376.00 | 1,251,806.00 |
| Volume of Water used for other | m3 | 71,108.00 | 72,074.00 | 95,341.00 | 79,685.00 | 46,867.00 |



Asela Water Supply Servise Enterprise

| | Karooraa fi Raawwii Hojii Gurguddoo Bara 2008-2012 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| La | Hojiiwwan gurguddoo | Sa | Raawwi 200 | Raawwi 200 | Raawwi 201 | Raawwi 201 | Raawwi 2012 | Karoo.Wa.5 | Raawwii Wa.5 | % |
| 1 | Bishaan Oomishame (M3 ) | M | 2,166,733 | 2,191,630 | 2,430,260 | 2,327,255 | 2,070,653 | 11,843,303 | 11,186,531 | 94 |
| 2 | Bishaan gurgurame (M3) | M | 1,480,466 | 1,421,963 | 1,380,367 | 1,382,691 | 1,204,939 | 9,645,318 | 6,870,426 | 71 |
| 3 | Bishaan faayidaa gara garaatiif oole | M | 71,108 | 72,074 | 95,341 | 79,685 | 46,867 | 357,825 | 365,075 | 102 |

Kan Qopheesse

Ballaxach Addunyaa Fayyisaa
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Kan Mirkaneesse

Kadiir Arabaa Aanaa
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## APPENDIX A: Node input data for Bentley water GEMS V8i

## Calculations for Assigning Water Demands to each node

Population of the town: 97118 people

Number of houses in Asella Town: 20475

Average Number of People in each house: 4.74

Total water consumption: 3429.61 $m^3$/day

Total water consumption: 35.314 l/p/day

| label | X (m) | Y (m) | Number of household around the node | Number of people for supply node | Base demand for supply node(L/s) |
|---|---|---|---|---|---|
| J-1 | 522,411.35 | 856,827.40 | | 0 | 0 |
| J-2 | 514,005.31 | 875,306.89 | | 0 | 0 |
| J-3 | 514,131.88 | 875,266.28 | | 0 | 0 |
| J-4 | 514,253.49 | 875,379.99 | | 0 | 0 |
| J-5 | 514,249.43 | 875,510.42 | 17 | 81 | 0.033 |
| J-6 | 514,253.91 | 875,646.75 | 22 | 104 | 0.043 |
| J-7 | 514,373.65 | 875,683.94 | 37 | 175 | 0.072 |
| J-8 | 514,260.01 | 875,242.69 | 18 | 85 | 0.035 |
| J-9 | 514,478.77 | 878,042.64 | 64 | 303 | 0.124 |
| J-10 | 514,543.21 | 878,015.06 | 21 | 100 | 0.041 |
| J-11 | 514,489.21 | 877,883.28 | 9 | 43 | 0.017 |
| J-12 | 514,440.59 | 877,762.81 | | 0 | 0 |
| J-13 | 514,397.02 | 877,645.25 | | 0 | 0 |
| J-14 | 514,343.06 | 877,520.10 | | 0 | 0 |
| J-15 | 514,186.32 | 877,504.69 | 53 | 251 | 0.103 |
| J-16 | 514,131.76 | 877,413.18 | 36 | 171 | 0.07 |
| J-17 | 514,077.69 | 877,294.22 | | 0 | 0 |
| J-18 | 514,007.40 | 877,161.75 | 79 | 374 | 0.153 |
| J-19 | 513,916.30 | 877,025.32 | | 0 | 0 |
| J-20 | 513,851.42 | 876,873.92 | | 0 | 0 |
| J-21 | 513,873.08 | 876,830.51 | | 0 | 0 |
| J-22 | 513,814.94 | 876,755.76 | 42 | 199 | 0.081 |
| J-23 | 513,772.38 | 876,552.20 | 55 | 261 | 0.107 |
| J-24 | 513,741.60 | 876,477.50 | 57 | 270 | 0.11 |
| J-25 | 513,741.63 | 876,383.12 | | 0 | 0 |
| J-26 | 513,743.25 | 876,233.10 | 23 | 109 | 0.045 |
| J-27 | 513,710.78 | 876,126.64 | | 0 | 0 |
| J-28 | 513,647.42 | 875,938.47 | | 0 | 0 |
| J-29 | 513,617.64 | 875,792.97 | | 0 | 0 |
| J-30 | 513,504.98 | 875,568.10 | | 0 | 0 |
| J-31 | 513,604.30 | 875,513.77 | 77 | 365 | 0.149 |
| J-32 | 513,745.02 | 875,441.66 | | 0 | 0 |
| J-33 | 513,818.34 | 875,363.93 | | 0 | 0 |
| J-34 | 514,021.97 | 881,378.97 | 43 | 204 | 0.083 |
| J-35 | 514,013.90 | 881,231.20 | | 0 | 0 |
| J-36 | 514,008.55 | 881,143.07 | 74 | 351 | 0.143 |
| J-37 | 513,155.97 | 876,628.80 | | 0 | 0 |
| J-38 | 513,119.55 | 876,631.43 | 30 | 142 | 0.058 |

| | | | | | | |
|---|---|---|---|---|---|---|
| J-39 | 513,074.61 | 876,657.80 | | 0 | 0 |
| J-40 | 513,047.54 | 876,704.09 | 43 | 204 | 0.083 |
| J-41 | 513,031.56 | 876,833.50 | | 0 | 0 |
| J-42 | 513,009.07 | 876,960.01 | 30 | 142 | 0.058 |
| J-43 | 513,213.33 | 877,201.83 | 45 | 213 | 0.087 |
| J-44 | 513,136.44 | 877,108.40 | 42 | 199 | 0.081 |
| J-45 | 513,268.15 | 877,277.01 | 36 | 171 | 0.07 |
| J-46 | 514,255.34 | 875,059.74 | | 0 | 0 |
| J-47 | 514,258.11 | 874,985.22 | 29 | 137 | 0.056 |
| J-48 | 513,904.16 | 875,372.26 | | 0 | 0 |
| J-49 | 515,511.00 | 878,265.24 | 20 | 95 | 0.039 |
| J-50 | 514,014.10 | 875,316.25 | 81 | 384 | 0.157 |
| J-51 | 514,131.78 | 875,277.71 | 84 | 398 | 0.163 |
| J-52 | 515,836.40 | 879,276.53 | 48 | 228 | 0.093 |
| J-53 | 514,479.12 | 877,887.16 | 104 | 493 | 0.201 |
| J-54 | 514,966.30 | 877,881.42 | | 0 | 0 |
| J-55 | 514,994.95 | 877,936.55 | | 0 | 0 |
| J-56 | 513,418.79 | 876,610.28 | 59 | 280 | 0.114 |
| J-57 | 514,431.89 | 877,765.25 | | 0 | 0 |
| J-58 | 515,808.40 | 879,140.96 | 94 | 446 | 0.182 |
| J-59 | 513,724.78 | 877,004.43 | 51 | 242 | 0.099 |
| J-60 | 514,430.67 | 878,017.65 | | 0 | 0 |
| J-61 | 514,327.12 | 877,924.85 | | 0 | 0 |
| J-62 | 514,523.07 | 877,411.14 | 43 | 204 | 0.083 |
| J-63 | 514,477.20 | 878,033.34 | 10 | 47 | 0.019 |
| J-64 | 514,820.78 | 877,700.28 | 41 | 194 | 0.079 |
| J-65 | 514,529.35 | 878,011.43 | | 0 | 0 |
| J-66 | 513,958.35 | 877,517.02 | | 0 | 0 |
| J-67 | 514,911.08 | 877,784.19 | 19 | 90 | 0.037 |
| J-68 | 514,477.26 | 877,528.69 | 39 | 185 | 0.076 |
| J-69 | 513,721.71 | 876,857.97 | | 0 | 0 |
| J-70 | 514,519.54 | 877,307.18 | | 0 | 0 |
| J-71 | 515,396.71 | 878,764.77 | | 0 | 0 |
| J-72 | 514,293.52 | 877,759.70 | 68 | 322 | 0.132 |
| J-73 | 514,309.31 | 877,754.46 | | 0 | 0 |
| J-74 | 514,850.48 | 877,679.55 | 50 | 237 | 0.097 |
| J-75 | 515,792.26 | 879,088.09 | 50 | 237 | 0.097 |
| J-76 | 514,446.65 | 877,529.05 | 90 | 427 | 0.174 |
| J-77 | 514,408.66 | 877,528.96 | 18 | 85 | 0.035 |
| J-78 | 514,473.83 | 877,435.01 | 109 | 517 | 0.211 |
| J-79 | 514,521.45 | 877,237.15 | 13 | 62 | 0.025 |
| J-80 | 515,131.25 | 877,971.74 | 75 | 356 | 0.145 |
| J-81 | 514,473.08 | 877,409.14 | 46 | 218 | 0.089 |
| J-82 | 514,384.36 | 877,648.63 | 32 | 152 | 0.062 |
| J-83 | 513,953.57 | 877,418.08 | | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| J-84 | 515,179.85 | 878,062.74 | 57 | 270 | 0.11 |
| J-85 | 515,274.46 | 877,900.68 | 27 | 128 | 0.052 |
| J-86 | 515,192.41 | 878,079.18 | 55 | 261 | 0.107 |
| J-87 | 514,319.96 | 877,097.62 | | 0 | 0 |
| J-88 | 513,584.76 | 876,572.29 | 40 | 190 | 0.077 |
| J-89 | 514,495.59 | 877,092.72 | 41 | 194 | 0.079 |
| J-90 | 514,943.01 | 877,608.86 | | 0 | 0 |
| J-91 | 514,120.84 | 877,646.89 | 10 | 47 | 0.019 |
| J-92 | 514,323.62 | 877,224.42 | | 0 | 0 |
| J-93 | 514,504.28 | 877,128.97 | | 0 | 0 |
| J-94 | 515,280.78 | 878,354.85 | | 0 | 0 |
| J-95 | 514,186.09 | 876,857.51 | | 0 | 0 |
| J-96 | 515,231.16 | 878,127.34 | | 0 | 0 |
| J-97 | 515,285.85 | 878,177.78 | | 0 | 0 |
| J-98 | 514,133.91 | 877,086.68 | | 0 | 0 |
| J-99 | 514,069.89 | 876,877.50 | 40 | 190 | 0.077 |
| J-100 | 513,809.08 | 876,931.25 | 62 | 294 | 0.12 |
| J-101 | 513,980.70 | 877,072.72 | 37 | 175 | 0.072 |
| J-102 | 513,738.56 | 876,695.18 | 54 | 256 | 0.105 |
| J-103 | 514,545.52 | 877,084.08 | 18 | 85 | 0.035 |
| J-104 | 515,717.29 | 878,979.92 | 58 | 275 | 0.112 |
| J-105 | 514,330.54 | 877,405.79 | 38 | 180 | 0.074 |
| J-106 | 514,333.70 | 877,532.01 | | 0 | 0 |
| J-107 | 514,094.97 | 877,521.32 | 51 | 242 | 0.099 |
| J-108 | 515,185.10 | 877,739.16 | | 0 | 0 |
| J-109 | 514,281.93 | 876,838.09 | 28 | 133 | 0.054 |
| J-110 | 513,968.70 | 877,239.13 | | 0 | 0 |
| J-111 | 513,882.86 | 876,680.95 | | 0 | 0 |
| J-112 | 515,684.23 | 878,933.21 | | 0 | 0 |
| J-113 | 515,270.88 | 878,040.16 | 34 | 161 | 0.066 |
| J-114 | 514,516.12 | 876,949.46 | 20 | 95 | 0.039 |
| J-115 | 514,275.18 | 877,653.88 | 40 | 190 | 0.077 |
| J-116 | 514,255.50 | 877,526.44 | 41 | 194 | 0.079 |
| J-117 | 513,753.54 | 876,534.27 | 74 | 351 | 0.143 |
| J-118 | 513,892.48 | 876,920.71 | 66 | 313 | 0.128 |
| J-119 | 513,886.97 | 876,902.83 | 40 | 190 | 0.077 |
| J-120 | 515,586.61 | 878,812.00 | 8 | 38 | 0.015 |
| J-121 | 514,298.18 | 876,470.64 | 23 | 109 | 0.045 |
| J-122 | 515,352.13 | 878,320.56 | 60 | 284 | 0.116 |
| J-123 | 515,359.49 | 878,340.35 | 40 | 190 | 0.077 |
| J-124 | 514,482.33 | 876,795.55 | 13 | 62 | 0.025 |
| J-125 | 514,683.89 | 877,064.72 | | 0 | 0 |
| J-126 | 514,418.02 | 876,496.98 | 34 | 161 | 0.066 |
| J-127 | 514,947.16 | 877,337.49 | 60 | 284 | 0.116 |
| J-128 | 513,799.36 | 876,492.83 | 40 | 190 | 0.077 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| J-129 | 516,022.02 | 878,915.04 | 30 | 142 | 0.058 |
| J-130 | 515,527.45 | 878,699.40 | 38 | 180 | 0.074 |
| J-131 | 514,975.16 | 877,383.07 | 98 | 465 | 0.19 |
| J-132 | 513,810.45 | 876,464.69 |  | 0 | 0 |
| J-133 | 513,754.98 | 876,382.20 | 58 | 275 | 0.112 |
| J-134 | 514,394.17 | 876,392.55 | 19 | 90 | 0.037 |
| J-135 | 513,604.72 | 875,524.98 |  | 0 | 0 |
| J-136 | 515,863.99 | 878,914.61 | 54 | 256 | 0.105 |
| J-137 | 513,878.97 | 876,407.41 | 46 | 218 | 0.089 |
| J-138 | 515,059.65 | 877,527.20 |  | 0 | 0 |
| J-139 | 513,753.12 | 875,448.92 | 40 | 190 | 0.077 |
| J-140 | 516,035.76 | 878,974.14 | 26 | 123 | 0.05 |
| J-141 | 513,895.36 | 876,400.73 | 9 | 43 | 0.017 |
| J-142 | 514,331.59 | 876,089.62 | 86 | 408 | 0.167 |
| J-143 | 515,050.60 | 877,510.51 |  | 0 | 0 |
| J-144 | 516,036.03 | 879,054.72 | 17 | 81 | 0.033 |
| J-145 | 515,457.33 | 878,468.20 | 61 | 289 | 0.118 |
| J-146 | 515,998.59 | 878,859.58 | 50 | 237 | 0.097 |
| J-147 | 515,817.27 | 878,552.07 | 40 | 190 | 0.077 |
| J-148 | 516,059.55 | 879,150.13 | 40 | 190 | 0.077 |
| J-149 | 514,176.11 | 876,449.00 | 49 | 232 | 0.095 |
| J-150 | 514,903.99 | 877,133.85 | 44 | 209 | 0.085 |
| J-151 | 515,652.56 | 878,632.38 | 50 | 237 | 0.097 |
| J-152 | 513,659.92 | 875,939.54 | 19 | 90 | 0.037 |
| J-153 | 513,511.49 | 875,572.53 | 8 | 38 | 0.015 |
| J-154 | 513,721.38 | 876,131.52 |  | 0 | 0 |
| J-155 | 515,325.09 | 877,670.78 | 35 | 166 | 0.068 |
| J-156 | 513,752.03 | 876,231.39 |  | 0 | 0 |
| J-157 | 516,119.45 | 879,284.90 | 20 | 95 | 0.039 |
| J-158 | 515,409.80 | 877,833.41 | 30 | 142 | 0.058 |
| J-159 | 515,372.70 | 877,641.52 |  | 0 | 0 |
| J-160 | 514,837.92 | 877,046.73 | 31 | 147 | 0.06 |
| J-161 | 513,935.73 | 876,401.59 | 10 | 47 | 0.019 |
| J-162 | 515,463.98 | 877,940.28 | 44 | 209 | 0.085 |
| J-163 | 513,581.98 | 875,708.97 | 10 | 47 | 0.019 |
| J-164 | 514,296.23 | 875,932.08 |  | 0 | 0 |
| J-165 | 515,087.86 | 877,486.37 | 69 | 327 | 0.134 |
| J-166 | 514,424.38 | 876,054.14 |  | 0 | 0 |
| J-167 | 514,046.83 | 876,422.92 |  | 0 | 0 |
| J-168 | 516,003.24 | 878,796.52 | 40 | 190 | 0.077 |
| J-169 | 515,469.79 | 877,807.04 | 20 | 95 | 0.039 |
| J-170 | 515,337.34 | 877,582.78 | 23 | 109 | 0.045 |
| J-171 | 513,621.56 | 875,785.56 |  | 0 | 0 |
| J-172 | 516,064.13 | 878,700.08 | 33 | 156 | 0.064 |
| J-173 | 514,262.49 | 875,785.35 |  | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| J-174 | 515,934.15 | 878,533.93 | 150 | 711 | 0.291 |
| J-175 | 515,525.86 | 877,911.88 | 161 | 763 | 0.312 |
| J-176 | 514,250.47 | 875,715.48 | 127 | 602 | 0.246 |
| J-177 | 516,012.32 | 878,535.89 | 142 | 673 | 0.275 |
| J-178 | 516,039.05 | 878,606.12 | | 0 | 0 |
| J-179 | 514,244.54 | 875,650.24 | 84 | 398 | 0.163 |
| J-180 | 514,776.07 | 876,734.08 | | 0 | 0 |
| J-181 | 514,272.96 | 875,659.20 | 70 | 332 | 0.136 |
| J-182 | 514,295.37 | 875,667.05 | 33 | 156 | 0.064 |
| J-183 | 515,580.96 | 878,004.88 | 13 | 62 | 0.025 |
| J-184 | 514,584.67 | 876,328.27 | 96 | 455 | 0.186 |
| J-185 | 515,687.69 | 878,164.76 | | 0 | 0 |
| J-186 | 515,149.46 | 877,455.20 | 24 | 114 | 0.046 |
| J-187 | 515,290.27 | 877,523.14 | | 0 | 0 |
| J-188 | 514,505.70 | 876,032.60 | 236 | 1119 | 0.457 |
| J-189 | 515,252.85 | 877,485.93 | 63 | 299 | 0.122 |
| J-190 | 514,243.84 | 875,509.78 | | 0 | 0 |
| J-191 | 514,251.30 | 875,249.08 | 244 | 1157 | 0.473 |
| J-192 | 515,617.33 | 878,055.28 | | 0 | 0 |
| J-193 | 514,684.02 | 876,504.92 | | 0 | 0 |
| J-194 | 514,585.60 | 876,208.96 | 90 | 427 | 0.174 |
| J-195 | 515,179.05 | 877,455.10 | 21 | 100 | 0.041 |
| J-196 | 514,246.76 | 875,378.52 | 57 | 270 | 0.11 |
| J-197 | 514,366.45 | 875,691.30 | 99 | 469 | 0.192 |
| J-198 | 514,629.96 | 876,309.73 | 64 | 303 | 0.124 |
| J-199 | 514,382.24 | 875,689.38 | 12 | 57 | 0.023 |
| J-200 | 514,051.04 | 879,820.32 | 240 | 1138 | 0.465 |
| J-201 | 513,712.97 | 879,046.55 | | 0 | 0 |
| J-202 | 513,699.08 | 879,188.28 | | 0 | 0 |
| J-203 | 513,591.51 | 879,244.35 | 145 | 687 | 0.281 |
| J-204 | 513,670.95 | 878,962.95 | 80 | 379 | 0.155 |
| J-205 | 513,662.31 | 878,812.01 | | 0 | 0 |
| J-206 | 513,677.29 | 878,952.77 | 50 | 237 | 0.097 |
| J-207 | 514,527.91 | 880,071.56 | 109 | 517 | 0.211 |
| J-208 | 513,759.03 | 879,858.54 | 250 | 1185 | 0.484 |
| J-209 | 513,690.91 | 878,875.17 | | 0 | 0 |
| J-210 | 513,766.82 | 879,151.96 | 4 | 19 | 0.008 |
| J-211 | 513,717.94 | 878,933.18 | 49 | 232 | 0.095 |
| J-212 | 513,737.27 | 879,837.41 | 65 | 308 | 0.126 |
| J-213 | 513,695.50 | 878,718.08 | | 0 | 0 |
| J-214 | 513,957.46 | 879,636.72 | 150 | 711 | 0.291 |
| J-215 | 513,949.80 | 879,821.29 | 35 | 166 | 0.068 |
| J-216 | 514,186.95 | 879,559.59 | | 0 | 0 |
| J-217 | 513,872.27 | 879,098.26 | | 0 | 0 |
| J-218 | 514,504.26 | 879,873.63 | 126 | 597 | 0.244 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| J-219 | 514,001.41 | 879,461.09 |  | 0 | 0 |
| J-220 | 513,784.13 | 879,814.30 | 80 | 379 | 0.155 |
| J-221 | 514,511.42 | 879,926.86 | 184 | 872 | 0.356 |
| J-222 | 514,114.46 | 879,563.11 | 53 | 251 | 0.103 |
| J-223 | 513,710.31 | 879,776.37 |  | 0 | 0 |
| J-224 | 513,750.07 | 878,656.23 |  | 0 | 0 |
| J-225 | 513,849.00 | 879,421.35 | 38 | 180 | 0.074 |
| J-226 | 513,878.89 | 879,391.71 | 19 | 90 | 0.037 |
| J-227 | 513,883.84 | 879,416.21 | 227 | 1076 | 0.44 |
| J-228 | 513,466.97 | 879,310.37 |  | 0 | 0 |
| J-229 | 513,898.88 | 879,828.24 | 23 | 109 | 0.045 |
| J-230 | 513,864.29 | 879,452.13 |  | 0 | 0 |
| J-231 | 513,894.43 | 879,513.54 | 89 | 422 | 0.172 |
| J-232 | 513,652.00 | 879,684.37 | 89 | 422 | 0.172 |
| J-233 | 513,925.70 | 879,367.74 |  | 0 | 0 |
| J-234 | 514,288.90 | 879,574.19 | 4 | 19 | 0.008 |
| J-235 | 513,865.82 | 878,538.93 | 74 | 351 | 0.143 |
| J-236 | 513,786.32 | 878,826.60 |  | 0 | 0 |
| J-237 | 514,694.21 | 879,988.12 | 71 | 337 | 0.138 |
| J-238 | 514,482.90 | 879,689.96 |  | 0 | 0 |
| J-239 | 514,138.66 | 879,399.13 | 129 | 611 | 0.25 |
| J-240 | 513,730.60 | 879,485.50 | 210 | 995 | 0.407 |
| J-241 | 513,719.32 | 879,642.37 | 160 | 758 | 0.31 |
| J-242 | 513,793.06 | 879,574.93 | 70 | 332 | 0.136 |
| J-243 | 513,580.28 | 879,403.90 | 40 | 190 | 0.077 |
| J-244 | 513,708.64 | 879,624.41 |  | 0 | 0 |
| J-245 | 513,656.42 | 879,524.16 | 224 | 1062 | 0.434 |
| J-246 | 513,928.32 | 879,226.75 |  | 0 | 0 |
| J-247 | 514,535.49 | 879,660.30 | 55 | 261 | 0.107 |
| J-248 | 513,985.04 | 878,457.45 | 63 | 299 | 0.122 |
| J-249 | 514,475.06 | 879,577.24 | 49 | 232 | 0.095 |
| J-250 | 514,111.46 | 879,272.78 | 100 | 474 | 0.194 |
| J-251 | 514,069.87 | 879,152.85 | 57 | 270 | 0.11 |
| J-252 | 514,029.98 | 879,017.41 |  | 0 | 0 |
| J-253 | 514,046.76 | 878,419.68 | 29 | 137 | 0.056 |
| J-254 | 514,052.07 | 878,392.49 | 102 | 483 | 0.198 |
| J-255 | 514,059.08 | 878,405.47 | 78 | 370 | 0.151 |
| J-256 | 514,618.62 | 879,612.35 |  | 0 | 0 |
| J-257 | 514,803.03 | 879,928.82 | 71 | 337 | 0.138 |
| J-258 | 514,463.20 | 879,454.19 | 50 | 237 | 0.097 |
| J-259 | 513,991.02 | 878,298.88 |  | 0 | 0 |
| J-260 | 514,006.40 | 878,714.87 | 185 | 877 | 0.358 |
| J-261 | 514,331.36 | 879,357.09 | 46 | 218 | 0.089 |
| J-262 | 515,166.20 | 880,303.00 | 40 | 190 | 0.077 |
| J-263 | 514,066.77 | 878,515.18 | 92 | 436 | 0.178 |

| | | | | | |
|---|---|---|---|---|---|
| J-264 | 513,753.33 | 877,891.59 | 62 | 294 | 0.12 |
| J-265 | 513,836.78 | 878,035.02 | 92 | 436 | 0.178 |
| J-266 | 513,909.06 | 878,168.70 | | 0 | 0 |
| J-267 | 514,023.02 | 878,284.19 | 128 | 607 | 0.248 |
| J-268 | 514,936.62 | 879,861.03 | 101 | 479 | 0.196 |
| J-269 | 514,087.35 | 878,537.23 | 7 | 33 | 0.014 |
| J-270 | 514,170.58 | 878,945.34 | | 0 | 0 |
| J-271 | 515,074.42 | 880,129.88 | 150 | 711 | 0.291 |
| J-272 | 514,237.33 | 879,065.43 | 45 | 213 | 0.087 |
| J-273 | 513,496.78 | 877,564.53 | | 0 | 0 |
| J-274 | 514,766.65 | 879,539.79 | | 0 | 0 |
| J-275 | 514,296.72 | 879,175.83 | 138 | 654 | 0.267 |
| J-276 | 514,908.69 | 879,805.55 | | 0 | 0 |
| J-277 | 514,445.79 | 879,317.38 | 83 | 393 | 0.161 |
| J-278 | 514,153.99 | 878,511.09 | 73 | 346 | 0.141 |
| J-279 | 513,660.73 | 877,777.55 | 24 | 114 | 0.046 |
| J-280 | 515,082.50 | 879,787.10 | 22 | 104 | 0.043 |
| J-281 | 514,078.68 | 878,261.72 | | 0 | 0 |
| J-282 | 514,833.78 | 879,664.65 | | 0 | 0 |
| J-283 | 514,165.31 | 878,640.29 | | 0 | 0 |
| J-284 | 514,143.43 | 878,599.68 | | 0 | 0 |
| J-285 | 514,428.18 | 879,190.72 | | 0 | 0 |
| J-286 | 514,228.26 | 878,476.09 | 84 | 398 | 0.163 |
| J-287 | 514,347.72 | 879,004.24 | | 0 | 0 |
| J-288 | 513,374.65 | 877,417.84 | 94 | 446 | 0.182 |
| J-289 | 514,674.20 | 879,358.55 | 38 | 180 | 0.074 |
| J-290 | 514,900.12 | 879,469.69 | 139 | 659 | 0.269 |
| J-291 | 514,428.72 | 879,112.13 | 42 | 199 | 0.081 |
| J-292 | 514,213.38 | 878,735.30 | | 0 | 0 |
| J-293 | 514,431.56 | 879,091.17 | 40 | 190 | 0.077 |
| J-294 | 514,133.31 | 878,254.93 | 104 | 493 | 0.201 |
| J-295 | 514,289.46 | 878,884.94 | | 0 | 0 |
| J-296 | 515,002.65 | 879,649.73 | 28 | 133 | 0.054 |
| J-297 | 514,222.29 | 878,307.08 | 61 | 289 | 0.118 |
| J-298 | 514,450.70 | 879,037.74 | 10 | 47 | 0.019 |
| J-299 | 514,585.95 | 879,181.24 | 48 | 228 | 0.093 |
| J-300 | 514,930.97 | 879,521.76 | | 0 | 0 |
| J-301 | 514,833.24 | 879,335.16 | | 0 | 0 |
| J-302 | 515,261.04 | 880,031.23 | 92 | 436 | 0.178 |
| J-303 | 515,217.03 | 879,719.51 | | 0 | 0 |
| J-304 | 514,530.35 | 879,072.30 | 13 | 62 | 0.025 |
| J-305 | 514,263.55 | 878,307.40 | | 0 | 0 |
| J-306 | 514,453.07 | 878,961.04 | 12 | 57 | 0.023 |
| J-307 | 514,452.86 | 878,949.78 | 63 | 299 | 0.122 |
| J-308 | 514,316.18 | 878,651.12 | 84 | 398 | 0.163 |

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|---|---|---|---|---|---|
| J-309 | 514,453.60 | 878,924.22 | | 0 | 0 |
| J-310 | 514,488.04 | 878,966.71 | 25 | 119 | 0.048 |
| J-311 | 514,771.30 | 879,215.06 | 24 | 114 | 0.046 |
| J-312 | 515,019.71 | 879,479.59 | 20 | 95 | 0.039 |
| J-313 | 514,404.09 | 878,826.15 | 55 | 261 | 0.107 |
| J-314 | 514,710.11 | 879,106.65 | | 0 | 0 |
| J-315 | 514,716.64 | 879,114.67 | | 0 | 0 |
| J-316 | 515,070.32 | 879,574.47 | 33 | 156 | 0.064 |
| J-317 | 514,657.17 | 879,003.87 | | 0 | 0 |
| J-318 | 515,127.17 | 879,548.64 | 18 | 85 | 0.035 |
| J-319 | 515,053.32 | 879,461.93 | | 0 | 0 |
| J-320 | 515,292.29 | 879,680.51 | 60 | 284 | 0.116 |
| J-321 | 515,270.96 | 879,636.88 | 55 | 261 | 0.107 |
| J-322 | 515,016.20 | 879,399.48 | | 0 | 0 |
| J-323 | 515,162.55 | 879,558.02 | | 0 | 0 |
| J-324 | 515,276.85 | 879,633.93 | 27 | 128 | 0.052 |
| J-325 | 515,393.63 | 879,957.52 | 48 | 228 | 0.093 |
| J-326 | 515,256.09 | 879,598.44 | 60 | 284 | 0.116 |
| J-327 | 514,588.78 | 878,867.80 | | 0 | 0 |
| J-328 | 515,248.13 | 879,577.00 | 60 | 284 | 0.116 |
| J-329 | 514,909.95 | 879,176.40 | 88 | 417 | 0.17 |
| J-330 | 515,201.43 | 879,551.39 | 94 | 446 | 0.182 |
| J-331 | 514,560.34 | 878,832.52 | | 0 | 0 |
| J-332 | 515,206.08 | 879,536.78 | 98 | 465 | 0.19 |
| J-333 | 514,889.33 | 879,164.87 | | 0 | 0 |
| J-334 | 514,870.98 | 879,140.81 | 50 | 237 | 0.097 |
| J-335 | 515,362.37 | 879,645.42 | | 0 | 0 |
| J-336 | 514,989.85 | 878,979.65 | 105 | 498 | 0.203 |
| J-337 | 515,182.47 | 879,491.98 | | 0 | 0 |
| J-338 | 514,696.85 | 878,303.73 | | 0 | 0 |
| J-339 | 515,018.06 | 878,884.80 | | 0 | 0 |
| J-340 | 515,051.24 | 878,948.90 | 145 | 687 | 0.281 |
| J-341 | 515,272.80 | 879,479.12 | | 0 | 0 |
| J-342 | 514,821.96 | 879,061.59 | 29 | 137 | 0.056 |
| J-343 | 514,817.12 | 879,052.23 | 44 | 209 | 0.085 |
| J-344 | 515,279.63 | 879,476.06 | 34 | 161 | 0.066 |
| J-345 | 514,728.90 | 878,328.68 | 78 | 370 | 0.151 |
| J-346 | 514,739.62 | 878,345.44 | 51 | 242 | 0.099 |
| J-347 | 515,143.05 | 879,415.43 | 37 | 175 | 0.072 |
| J-348 | 515,405.10 | 879,622.52 | 40 | 190 | 0.077 |
| J-349 | 515,435.05 | 879,811.19 | 20 | 95 | 0.039 |
| J-350 | 515,288.51 | 879,456.93 | | 0 | 0 |
| J-351 | 515,257.74 | 879,452.41 | 37 | 175 | 0.072 |
| J-352 | 514,962.64 | 878,785.97 | | 0 | 0 |
| J-353 | 515,454.61 | 879,873.13 | 68 | 322 | 0.132 |

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|---|---|---|---|---|---|
| J-354 | 514,754.36 | 878,339.62 | 41 | 194 | 0.079 |
| J-355 | 514,762.68 | 878,946.66 | | 0 | 0 |
| J-356 | 515,104.35 | 879,342.83 | 77 | 365 | 0.149 |
| J-357 | 514,622.68 | 878,718.04 | 165 | 782 | 0.32 |
| J-358 | 514,663.89 | 878,286.23 | | 0 | 0 |
| J-359 | 515,305.36 | 879,433.37 | 46 | 218 | 0.089 |
| J-360 | 514,664.88 | 878,270.16 | 158 | 749 | 0.306 |
| J-361 | 515,099.87 | 879,317.03 | | 0 | 0 |
| J-362 | 514,959.06 | 879,140.79 | 72 | 341 | 0.139 |
| J-363 | 514,677.65 | 878,722.46 | | 0 | 0 |
| J-364 | 515,125.64 | 879,327.85 | | 0 | 0 |
| J-365 | 514,790.64 | 878,388.51 | 44 | 209 | 0.085 |
| J-366 | 515,000.55 | 879,147.61 | | 0 | 0 |
| J-367 | 515,072.93 | 879,275.96 | 35 | 166 | 0.068 |
| J-368 | 514,859.64 | 878,594.78 | 89 | 422 | 0.172 |
| J-369 | 514,808.91 | 878,337.06 | 87 | 412 | 0.169 |
| J-370 | 514,789.26 | 878,460.59 | 200 | 948 | 0.387 |
| J-371 | 514,769.55 | 878,444.44 | | 0 | 0 |
| J-372 | 514,436.92 | 878,257.64 | 50 | 237 | 0.097 |
| J-373 | 514,629.49 | 878,261.35 | 150 | 711 | 0.291 |
| J-374 | 514,629.92 | 878,220.12 | 123 | 583 | 0.238 |
| J-375 | 514,699.02 | 878,575.73 | | 0 | 0 |
| J-376 | 514,788.49 | 878,239.97 | 62 | 294 | 0.12 |
| J-377 | 514,775.10 | 878,179.07 | | 0 | 0 |
| J-378 | 515,116.43 | 879,079.04 | 29 | 137 | 0.056 |
| J-379 | 514,620.09 | 878,187.10 | | 0 | 0 |
| J-380 | 515,382.15 | 879,152.47 | | 0 | 0 |
| J-381 | 515,184.88 | 879,295.70 | | 0 | 0 |
| J-382 | 514,751.11 | 878,104.94 | | 0 | 0 |
| J-383 | 515,616.65 | 879,518.75 | | 0 | 0 |
| J-384 | 515,220.94 | 879,277.58 | | 0 | 0 |
| J-385 | 515,464.18 | 879,110.23 | | 0 | 0 |
| J-386 | 515,178.93 | 879,200.97 | | 0 | 0 |
| J-387 | 515,211.17 | 879,260.15 | | 0 | 0 |
| J-388 | 514,393.67 | 878,118.78 | | 0 | 0 |
| J-389 | 514,510.64 | 878,242.98 | | 0 | 0 |
| J-390 | 514,562.37 | 878,213.17 | 50 | 237 | 0.097 |
| J-391 | 515,778.13 | 879,431.73 | | 0 | 0 |
| J-392 | 515,304.33 | 878,811.36 | 105 | 498 | 0.203 |
| J-393 | 514,304.71 | 881,898.58 | | 0 | 0 |
| J-394 | 513,678.73 | 881,718.32 | | 0 | 0 |
| J-395 | 513,697.88 | 881,710.46 | | 0 | 0 |
| J-396 | 514,258.71 | 881,850.56 | | 0 | 0 |
| J-397 | 514,366.45 | 881,796.03 | | 0 | 0 |
| J-398 | 514,238.28 | 881,807.18 | | 0 | 0 |

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|---|---|---|---|---|---|
| J-399 | 513,888.87 | 881,629.77 | 27 | 128 | 0.052 |
| J-400 | 513,796.31 | 881,648.30 | | 0 | 0 |
| J-401 | 514,230.91 | 881,766.87 | 28 | 133 | 0.054 |
| J-402 | 514,162.61 | 881,711.16 | | 0 | 0 |
| J-403 | 514,170.16 | 881,705.00 | | 0 | 0 |
| J-404 | 514,179.17 | 881,703.21 | 90 | 427 | 0.174 |
| J-405 | 513,959.71 | 881,627.17 | | 0 | 0 |
| J-406 | 514,080.11 | 881,646.23 | 18 | 85 | 0.035 |
| J-407 | 514,030.54 | 881,624.56 | 42 | 199 | 0.081 |
| J-408 | 514,055.32 | 881,633.22 | 43 | 204 | 0.083 |
| J-409 | 514,408.68 | 881,719.25 | | 0 | 0 |
| J-410 | 514,226.32 | 881,708.38 | | 0 | 0 |
| J-411 | 514,396.77 | 881,707.08 | | 0 | 0 |
| J-412 | 512,892.90 | 879,908.17 | | 0 | 0 |
| J-413 | 513,694.72 | 881,491.11 | | 0 | 0 |
| J-414 | 512,871.83 | 879,815.95 | | 0 | 0 |
| J-415 | 513,850.83 | 881,480.63 | | 0 | 0 |
| J-416 | 512,968.64 | 879,842.39 | 89 | 422 | 0.172 |
| J-417 | 514,741.54 | 881,948.30 | 14 | 66 | 0.027 |
| J-418 | 513,440.16 | 880,381.38 | | 0 | 0 |
| J-419 | 512,837.42 | 879,674.27 | | 0 | 0 |
| J-420 | 513,212.92 | 880,190.12 | 19 | 90 | 0.037 |
| J-421 | 514,004.25 | 881,469.34 | | 0 | 0 |
| J-422 | 514,212.57 | 881,537.17 | | 0 | 0 |
| J-423 | 513,162.30 | 879,937.04 | | 0 | 0 |
| J-424 | 514,025.97 | 881,468.19 | 30 | 142 | 0.058 |
| J-425 | 514,039.81 | 881,467.59 | | 0 | 0 |
| J-426 | 514,488.48 | 881,575.34 | | 0 | 0 |
| J-427 | 513,185.53 | 880,053.18 | | 0 | 0 |
| J-428 | 513,158.14 | 879,916.24 | | 0 | 0 |
| J-429 | 513,049.66 | 879,797.52 | | 0 | 0 |
| J-430 | 512,798.74 | 879,514.78 | | 0 | 0 |
| J-431 | 514,725.81 | 881,506.92 | 10 | 47 | 0.019 |
| J-432 | 514,957.22 | 882,005.45 | | 0 | 0 |
| J-433 | 514,913.79 | 881,988.63 | | 0 | 0 |
| J-434 | 513,250.29 | 880,182.70 | | 0 | 0 |
| J-435 | 514,091.81 | 881,433.50 | | 0 | 0 |
| J-436 | 514,142.97 | 881,399.11 | | 0 | 0 |
| J-437 | 513,368.59 | 880,262.10 | 16 | 76 | 0.031 |
| J-438 | 514,155.90 | 881,395.53 | | 0 | 0 |
| J-439 | 513,308.10 | 880,153.81 | | 0 | 0 |
| J-440 | 513,311.76 | 880,167.30 | | 0 | 0 |
| J-441 | 514,198.27 | 881,394.03 | | 0 | 0 |
| J-442 | 514,689.08 | 881,454.39 | 16 | 76 | 0.031 |
| J-443 | 513,247.78 | 879,906.88 | | 0 | 0 |

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|---|---|---|---|---|---|
| J-444 | 513,335.42 | 880,142.10 | 42 | 199 | 0.081 |
| J-445 | 514,300.44 | 881,382.03 | | 0 | 0 |
| J-446 | 513,521.00 | 880,478.18 | 11 | 52 | 0.021 |
| J-447 | 514,250.27 | 881,392.40 | 17 | 81 | 0.033 |
| J-448 | 514,753.55 | 881,247.90 | 39 | 185 | 0.076 |
| J-449 | 513,608.01 | 880,523.40 | | 0 | 0 |
| J-450 | 513,326.56 | 880,082.21 | | 0 | 0 |
| J-451 | 513,582.76 | 880,384.98 | | 0 | 0 |
| J-452 | 514,337.87 | 881,352.61 | | 0 | 0 |
| J-453 | 514,688.88 | 881,189.49 | | 0 | 0 |
| J-454 | 514,238.70 | 881,269.49 | | 0 | 0 |
| J-455 | 513,164.70 | 879,768.90 | | 0 | 0 |
| J-456 | 513,647.68 | 880,297.59 | | 0 | 0 |
| J-457 | 514,357.62 | 881,334.68 | 51 | 242 | 0.099 |
| J-458 | 514,048.12 | 880,732.98 | 10 | 47 | 0.019 |
| J-459 | 513,713.43 | 877,507.89 | 24 | 114 | 0.046 |
| J-460 | 513,579.11 | 880,256.34 | | 0 | 0 |
| J-461 | 513,699.70 | 880,569.62 | 50 | 237 | 0.097 |
| J-462 | 513,302.88 | 879,976.39 | 13 | 62 | 0.025 |
| J-463 | 513,659.24 | 880,292.88 | | 0 | 0 |
| J-464 | 514,042.26 | 880,712.09 | | 0 | 0 |
| J-465 | 514,819.89 | 881,748.88 | | 0 | 0 |
| J-466 | 513,289.03 | 879,901.28 | 11 | 52 | 0.021 |
| J-467 | 514,939.10 | 881,355.12 | | 0 | 0 |
| J-468 | 514,677.89 | 877,870.66 | 19 | 90 | 0.037 |
| J-469 | 513,824.11 | 880,638.79 | | 0 | 0 |
| J-470 | 514,047.75 | 880,778.31 | | 0 | 0 |
| J-471 | 513,857.68 | 880,644.33 | | 0 | 0 |
| J-472 | 513,789.21 | 880,602.54 | 14 | 66 | 0.027 |
| J-473 | 513,441.94 | 880,118.19 | | 0 | 0 |
| J-474 | 513,450.15 | 880,136.42 | | 0 | 0 |
| J-475 | 513,744.20 | 880,402.83 | | 0 | 0 |
| J-476 | 514,643.73 | 881,423.82 | 22 | 104 | 0.043 |
| J-477 | 513,825.17 | 880,607.58 | 23 | 109 | 0.045 |
| J-478 | 514,588.89 | 877,782.39 | | 0 | 0 |
| J-479 | 513,490.49 | 880,180.64 | | 0 | 0 |
| J-480 | 514,230.18 | 881,148.00 | 32 | 152 | 0.062 |
| J-481 | 513,747.14 | 880,413.62 | 24 | 114 | 0.046 |
| J-482 | 513,717.52 | 880,361.26 | 49 | 232 | 0.095 |
| J-483 | 514,597.11 | 881,364.95 | 27 | 128 | 0.052 |
| J-484 | 513,548.89 | 880,209.54 | | 0 | 0 |
| J-485 | 514,712.08 | 878,083.94 | 17 | 81 | 0.033 |
| J-486 | 513,268.87 | 879,793.19 | 81 | 384 | 0.157 |
| J-487 | 512,987.35 | 879,458.82 | 16 | 76 | 0.031 |
| J-488 | 514,921.49 | 881,284.70 | 73 | 346 | 0.141 |

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|---|---|---|---|---|---|
| J-489 | 514,051.11 | 880,823.63 | | 0 | 0 |
| J-490 | 514,387.14 | 881,284.07 | | 0 | 0 |
| J-491 | 514,167.48 | 881,014.04 | 34 | 161 | 0.066 |
| J-492 | 514,915.50 | 881,426.13 | 51 | 242 | 0.099 |
| J-493 | 513,507.98 | 880,168.90 | | 0 | 0 |
| J-494 | 513,721.16 | 880,426.84 | | 0 | 0 |
| J-495 | 514,631.83 | 877,893.69 | | 0 | 0 |
| J-496 | 513,695.36 | 880,160.72 | 24 | 114 | 0.046 |
| J-497 | 514,238.79 | 881,099.41 | 26 | 123 | 0.05 |
| J-498 | 514,918.11 | 881,270.61 | 18 | 85 | 0.035 |
| J-499 | 513,913.59 | 880,647.28 | | 0 | 0 |
| J-500 | 513,829.09 | 880,575.92 | | 0 | 0 |
| J-501 | 514,420.50 | 881,236.59 | | 0 | 0 |
| J-502 | 514,783.02 | 881,158.41 | | 0 | 0 |
| J-503 | 514,870.33 | 881,591.79 | 47 | 223 | 0.091 |
| J-504 | 513,832.56 | 880,567.12 | | 0 | 0 |
| J-505 | 513,712.56 | 877,398.79 | 22 | 104 | 0.043 |
| J-506 | 514,193.91 | 880,996.37 | | 0 | 0 |
| J-507 | 513,729.97 | 880,198.70 | | 0 | 0 |
| J-508 | 514,441.23 | 881,210.72 | 55 | 261 | 0.107 |
| J-509 | 514,896.69 | 881,458.26 | 47 | 223 | 0.091 |
| J-510 | 514,877.36 | 881,545.11 | 69 | 327 | 0.134 |
| J-511 | 514,520.61 | 881,279.20 | | 0 | 0 |
| J-512 | 514,338.62 | 881,123.48 | | 0 | 0 |
| J-513 | 514,262.16 | 881,057.34 | 78 | 370 | 0.151 |
| J-514 | 514,471.67 | 881,183.14 | 17 | 81 | 0.033 |
| J-515 | 513,267.87 | 876,645.88 | 153 | 725 | 0.296 |
| J-516 | 514,105.54 | 880,919.06 | 48 | 228 | 0.093 |
| J-517 | 513,741.42 | 880,183.55 | | 0 | 0 |
| J-518 | 513,254.67 | 879,722.67 | | 0 | 0 |
| J-519 | 514,015.46 | 880,577.78 | | 0 | 0 |
| J-520 | 514,642.52 | 881,238.36 | 23 | 109 | 0.045 |
| J-521 | 514,882.05 | 881,207.30 | | 0 | 0 |
| J-522 | 514,009.55 | 880,660.36 | | 0 | 0 |
| J-523 | 513,984.02 | 880,654.57 | 15 | 71 | 0.029 |
| J-524 | 515,241.89 | 881,740.70 | | 0 | 0 |
| J-525 | 513,800.44 | 880,292.78 | 22 | 104 | 0.043 |
| J-526 | 514,713.45 | 877,837.79 | 51 | 242 | 0.099 |
| J-527 | 512,999.47 | 878,915.89 | | 0 | 0 |
| J-528 | 513,960.19 | 880,504.21 | | 0 | 0 |
| J-529 | 513,551.88 | 880,073.12 | | 0 | 0 |
| J-530 | 514,916.91 | 881,219.46 | | 0 | 0 |
| J-531 | 514,514.95 | 881,146.69 | | 0 | 0 |
| J-532 | 514,809.29 | 881,128.66 | 11 | 52 | 0.021 |
| J-533 | 514,068.49 | 877,746.09 | 52 | 246 | 0.101 |

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|---|---|---|---|---|---|
| J-534 | 515,151.12 | 881,688.09 | | 0 | 0 |
| J-535 | 513,876.06 | 880,399.03 | | 0 | 0 |
| J-536 | 513,521.62 | 880,033.33 | | 0 | 0 |
| J-537 | 515,048.35 | 881,645.25 | 67 | 318 | 0.13 |
| J-538 | 514,629.55 | 880,942.28 | 32 | 152 | 0.062 |
| J-539 | 514,869.71 | 880,887.94 | 85 | 403 | 0.165 |
| J-540 | 514,646.33 | 880,907.99 | | 0 | 0 |
| J-541 | 513,651.84 | 880,114.26 | | 0 | 0 |
| J-542 | 514,036.61 | 877,709.17 | | 0 | 0 |
| J-543 | 514,582.26 | 881,042.24 | 24 | 114 | 0.046 |
| J-544 | 515,392.75 | 881,835.73 | | 0 | 0 |
| J-545 | 514,870.60 | 881,169.69 | 50 | 237 | 0.097 |
| J-546 | 514,930.08 | 881,187.98 | | 0 | 0 |
| J-547 | 514,860.44 | 881,168.42 | 87 | 412 | 0.169 |
| J-548 | 514,674.73 | 880,867.16 | | 0 | 0 |
| J-549 | 513,416.24 | 879,846.35 | | 0 | 0 |
| J-550 | 514,558.49 | 877,704.30 | | 0 | 0 |
| J-551 | 514,541.18 | 881,122.95 | | 0 | 0 |
| J-552 | 514,551.43 | 881,116.39 | 3 | 14 | 0.006 |
| J-553 | 514,552.52 | 881,088.40 | | 0 | 0 |
| J-554 | 514,536.53 | 881,102.58 | | 0 | 0 |
| J-555 | 512,996.25 | 878,845.49 | | 0 | 0 |
| J-556 | 515,497.73 | 881,901.50 | | 0 | 0 |
| J-557 | 514,552.41 | 877,781.01 | 84 | 398 | 0.163 |
| J-558 | 514,507.49 | 880,942.30 | | 0 | 0 |
| J-559 | 514,522.39 | 880,936.13 | 38 | 180 | 0.074 |
| J-560 | 513,595.41 | 880,039.08 | 150 | 711 | 0.291 |
| J-561 | 514,943.87 | 881,166.66 | | 0 | 0 |
| J-562 | 513,063.29 | 879,060.52 | | 0 | 0 |
| J-563 | 513,228.91 | 879,594.21 | | 0 | 0 |
| J-564 | 513,190.97 | 879,419.78 | 29 | 137 | 0.056 |
| J-565 | 513,107.17 | 878,871.71 | | 0 | 0 |
| J-566 | 514,918.20 | 878,097.04 | 93 | 441 | 0.18 |
| J-567 | 515,606.41 | 881,970.55 | 102 | 483 | 0.198 |
| J-568 | 513,186.90 | 879,392.90 | 29 | 137 | 0.056 |
| J-569 | 514,407.08 | 880,851.09 | | 0 | 0 |
| J-570 | 513,087.15 | 879,115.96 | | 0 | 0 |
| J-571 | 514,434.78 | 880,801.85 | 21 | 100 | 0.041 |
| J-572 | 514,717.12 | 880,803.37 | 45 | 213 | 0.087 |
| J-573 | 513,233.05 | 878,890.08 | 44 | 209 | 0.085 |
| J-574 | 513,127.91 | 879,207.38 | 102 | 483 | 0.198 |
| J-575 | 514,974.95 | 878,208.83 | 83 | 393 | 0.161 |
| J-576 | 514,612.78 | 880,712.87 | 32 | 152 | 0.062 |
| J-577 | 513,649.74 | 879,998.73 | 73 | 346 | 0.141 |
| J-578 | 514,114.61 | 880,445.19 | 22 | 104 | 0.043 |

| | | | | | |
|---|---|---|---|---|---|
| J-579 | 514,139.52 | 880,475.89 | | 0 | 0 |
| J-580 | 515,011.48 | 881,095.31 | | 0 | 0 |
| J-581 | 514,736.42 | 880,773.85 | 23 | 109 | 0.045 |
| J-582 | 514,749.45 | 877,787.97 | | 0 | 0 |
| J-583 | 513,858.41 | 880,103.48 | 83 | 393 | 0.161 |
| J-584 | 513,489.01 | 879,796.66 | | 0 | 0 |
| J-585 | 513,164.09 | 879,310.62 | | 0 | 0 |
| J-586 | 513,287.31 | 878,846.08 | | 0 | 0 |
| J-587 | 514,553.09 | 880,291.93 | 12 | 57 | 0.023 |
| J-588 | 514,559.66 | 880,358.58 | | 0 | 0 |
| J-589 | 513,826.49 | 877,513.40 | | 0 | 0 |
| J-590 | 514,569.23 | 880,361.25 | 16 | 76 | 0.031 |
| J-591 | 514,425.34 | 880,210.47 | 33 | 156 | 0.064 |
| J-592 | 514,411.43 | 880,229.91 | 18 | 85 | 0.035 |
| J-593 | 515,031.97 | 880,951.54 | 50 | 237 | 0.097 |
| J-594 | 513,307.28 | 878,839.37 | | 0 | 0 |
| J-595 | 513,779.97 | 880,007.96 | 52 | 246 | 0.101 |
| J-596 | 514,516.09 | 880,630.64 | 69 | 327 | 0.134 |
| J-597 | 514,013.26 | 880,304.46 | 48 | 228 | 0.093 |
| J-598 | 513,330.65 | 878,837.94 | | 0 | 0 |
| J-599 | 515,037.17 | 878,331.02 | | 0 | 0 |
| J-600 | 515,028.20 | 880,597.09 | | 0 | 0 |
| J-601 | 515,116.13 | 880,980.19 | 45 | 213 | 0.087 |
| J-602 | 514,607.94 | 880,324.80 | 40 | 190 | 0.077 |
| J-603 | 514,803.15 | 880,676.98 | | 0 | 0 |
| J-604 | 513,710.71 | 879,932.05 | | 0 | 0 |
| J-605 | 514,545.52 | 880,565.57 | | 0 | 0 |
| J-606 | 513,712.37 | 877,287.92 | | 0 | 0 |
| J-607 | 514,331.61 | 880,150.11 | | 0 | 0 |
| J-608 | 514,565.60 | 880,420.48 | 74 | 351 | 0.143 |
| J-609 | 515,067.20 | 880,631.41 | 129 | 611 | 0.25 |
| J-610 | 513,934.73 | 880,196.41 | 54 | 256 | 0.105 |
| J-611 | 514,634.60 | 880,306.22 | | 0 | 0 |
| J-612 | 514,204.41 | 880,371.76 | 23 | 109 | 0.045 |
| J-613 | 515,087.74 | 880,607.46 | 97 | 460 | 0.188 |
| J-614 | 513,948.19 | 880,019.66 | | 0 | 0 |
| J-615 | 515,102.60 | 878,448.26 | | 0 | 0 |
| J-616 | 513,568.53 | 879,742.36 | 40 | 190 | 0.077 |
| J-617 | 514,575.67 | 880,462.70 | 62 | 294 | 0.12 |
| J-618 | 515,207.29 | 880,861.79 | | 0 | 0 |
| J-619 | 513,439.36 | 878,874.48 | 51 | 242 | 0.099 |
| J-620 | 514,860.44 | 880,592.84 | | 0 | 0 |
| J-621 | 514,351.99 | 880,262.99 | | 0 | 0 |
| J-622 | 513,981.05 | 879,994.21 | 59 | 280 | 0.114 |
| J-623 | 514,287.25 | 880,116.24 | | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| J-624 | 514,849.31 | 877,972.72 | 48 | 228 | 0.093 |
| J-625 | 514,210.18 | 880,066.38 | 28 | 133 | 0.054 |
| J-626 | 514,816.24 | 880,424.80 | | 0 | 0 |
| J-627 | 514,773.82 | 880,398.32 | | 0 | 0 |
| J-628 | 515,146.67 | 880,732.64 | 46 | 218 | 0.089 |
| J-629 | 514,080.02 | 879,932.95 | 82 | 389 | 0.159 |
| J-630 | 514,103.60 | 880,236.77 | 41 | 194 | 0.079 |
| J-631 | 514,920.62 | 880,505.28 | | 0 | 0 |
| J-632 | 514,532.22 | 877,616.52 | 34 | 161 | 0.066 |
| J-633 | 514,141.51 | 880,008.39 | | 0 | 0 |
| J-634 | 513,586.68 | 878,922.39 | | 0 | 0 |
| J-635 | 513,720.84 | 879,646.89 | 39 | 185 | 0.076 |
| J-636 | 513,957.28 | 877,615.33 | | 0 | 0 |
| J-637 | 515,868.28 | 879,385.71 | | 0 | 0 |
| J-638 | 514,784.78 | 877,735.47 | 52 | 246 | 0.101 |
| J-639 | 513,731.25 | 877,131.22 | 34 | 161 | 0.066 |
| J-640 | 515,159.75 | 878,419.13 | | 0 | 0 |
| J-641 | 514,138.34 | 877,731.16 | 40 | 190 | 0.077 |
| J-642 | 513,937.05 | 877,517.14 | | 0 | 0 |
| J-643 | 514,382.21 | 877,999.54 | | 0 | 0 |
| J-644 | 515,092.69 | 878,135.09 | | 0 | 0 |
| J-645 | 515,037.53 | 878,025.20 | 8 | 38 | 0.015 |
| J-646 | 514,348.67 | 877,973.20 | | 0 | 0 |
| J-647 | 513,866.45 | 878,785.97 | 34 | 161 | 0.066 |
| J-648 | 513,955.28 | 876,897.21 | 23 | 109 | 0.045 |
| J-649 | 515,017.32 | 880,014.12 | 88 | 417 | 0.17 |
| J-650 | 514,474.05 | 877,466.01 | 0 | | 0 |
| **Total number of house hold : 20475** | | | | | |

**Appendix B: Projected water demand for Asella town**

| **Description** | Unit | **Years** | | | | |
|---|---|---|---|---|---|---|
| | | **2020** | **2025** | **2030** | **2035** | **2040** |
| Total Population | | 97118 | 118620 | 143441 | 171730 | 203552 |
| **Domestic Water Demand** | | | | | | |
| **Percentage of population served by** | | | | | | |
| **HC** | % | 6.10 | 15.00 | 17.00 | 19.00 | 21.00 |
| **YC** | % | 48.60 | 50.00 | 55.00 | 61.00 | 67.00 |
| **PT** | % | 44.50 | 35.00 | 28.00 | 20.00 | 12.00 |
| **Population served by** | | | | | | |
| **HC** | No | 5924 | 17793 | 24385 | 32629 | 42746 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **YC** | No | 47199 | 59310 | 78892 | 104755 | 136380 |
| **PT** | No | 43217 | 41517 | 40163 | 34346 | 24426 |
| **Per capita demand by Service Type** | | | | | | |
| **HC** | l/c/d | **70** | 78 | 85 | 93 | 100 |
| **YC** | l/c/d | 40 | 45 | 50 | 55 | 60 |
| **PT** | l/c/d | 25 | 28 | 30 | 33 | 35 |
| **Total domestic water demand** | m3 /d | 3383.09 | 5189.61 | 7222.25 | 9895.93 | 13312.32 |
| Socio-economic factor | | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Climate factor | | 1 | 1 | 1 | 1 | 1 |
| **Adjusted Total Domestic Water Demand** | m3 /d | 3552.25 | 5449.09 | 7583.36 | 10390.73 | 13977.93 |
| | l/s | 41.11 | 63.07 | 87.77 | 120.26 | 161.78 |
| **Non Domestic Water Demand** | | | | | | |
| Public & Institutional WaterDemand (10% of DWD) | m3 /d | 355.22 | 544.91 | 758.34 | 1039.07 | 1397.79 |
| | l/s | 4.11 | 6.31 | 8.78 | 12.03 | 16.18 |
| Commercial Water Demand (10% of DWD) | m3 /d | 355.22 | 544.91 | 758.34 | 1039.07 | 1397.79 |
| | l/s | 4.11 | 6.31 | 8.78 | 12.03 | 16.18 |
| Industrial Water Demand (30% of DWD) | m3 /d | 1065.67 | 1634.73 | 2275.01 | 3117.22 | 4193.38 |
| | l/s | 12.33 | 18.92 | 26.33 | 36.08 | 48.53 |
| **Total Non Domestic Water Demand** | m3 /d | 1776.12 | 2724.55 | 3791.68 | 5195.36 | 6988.97 |
| | l/s | 20.56 | 31.53 | 43.89 | 60.13 | 80.89 |
| Non Revenue Water = % of Domestic and Non Domestic Water Demand | % | 40.00 | 35.00 | 30.00 | 27.50 | 25.00 |
| | m3 /d | 2131.35 | 2860.77 | 3412.51 | 4286.18 | 5241.72 |
| | l/s | 24.67 | 33.11 | 39.50 | 49.61 | 60.67 |
| **Total Average Day Water Demand** | m3 /d | 7459.72 | 11034.41 | 14787.55 | 19872.27 | 26208.62 |
| | l/s | 86.34 | 127.71 | 171.15 | 230.00 | 303.34 |
| | l/c/day | 76.81 | 93.02 | 103.09 | 115.72 | 128.76 |
| **Maximum Day Demand** | MDf | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| | m3 /d | 8951.66 | 13241.30 | 17745.06 | 23846.72 | 31450.35 |
| | l/s | 103.61 | 153.26 | 205.38 | 276.00 | 364.01 |
| | l/c/day | 92.17 | 111.63 | 123.71 | 138.86 | 154.51 |
| **Peak Hour Day Demand** | PHf | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| | m3 /d | 13427.49 | 19861.94 | 26617.59 | 35770.09 | 47175.52 |
| | l/s | 155.41 | 229.88 | 308.07 | 414.01 | 546.01 |
| | l/c/day | 138.26 | 167.44 | 185.56 | 208.29 | 231.76 |

## Appendix C: Extended period state Analysis Table for Nodes (Junctions) at maximum hour consumption

Junction FlexTable: Table - 1

**Current Time:  14.000 hours**

| Label | X (m) | Y (m) | Elevation (m) | Demand (L/s) | Pressure (m H2O) | Hydraulic Grade (m) |
|---|---|---|---|---|---|---|
| J-1 | 522,411.35 | 856,827.40 | 2,485.00 | 0.0000 | 82.40 | 2,567.57 |
| J-2 | 514,005.31 | 875,306.89 | 2,524.00 | 0.0000 | 38.37 | 2,562.45 |
| J-3 | 514,131.88 | 875,266.28 | 2,536.00 | 0.0000 | 26.15 | 2,562.20 |
| J-4 | 514,253.49 | 875,379.99 | 2,538.57 | 0.0000 | 23.09 | 2,561.71 |
| J-5 | 514,249.43 | 875,510.42 | 2,538.57 | 0.0000 | 22.85 | 2,561.47 |
| J-6 | 514,253.91 | 875,646.75 | 2,538.57 | 0.0000 | 22.60 | 2,561.22 |
| J-7 | 514,373.65 | 875,683.94 | 2,538.57 | 0.0000 | 22.37 | 2,560.99 |
| J-8 | 514,260.01 | 875,242.69 | 2,535.00 | 0.0000 | 26.91 | 2,561.96 |
| J-9 | 514,478.77 | 878,042.64 | 2,469.00 | 0.0000 | 16.01 | 2,485.04 |
| J-10 | 514,543.21 | 878,015.06 | 2,471.00 | 0.0000 | 14.95 | 2,485.98 |
| J-11 | 514,489.21 | 877,883.28 | 2,470.00 | 0.0000 | 17.86 | 2,487.89 |
| J-12 | 514,440.59 | 877,762.81 | 2,474.00 | 0.0000 | 15.60 | 2,489.64 |
| J-13 | 514,397.02 | 877,645.25 | 2,484.00 | 0.0000 | 7.30 | 2,491.32 |
| J-14 | 514,343.06 | 877,520.10 | 2,493.40 | 0.0000 | -0.26 | 2,493.14 |
| J-15 | 514,186.32 | 877,504.69 | 2,493.00 | 0.0000 | 2.25 | 2,495.26 |
| J-16 | 514,131.76 | 877,413.18 | 2,492.00 | 0.0000 | 4.67 | 2,496.68 |
| J-17 | 514,077.69 | 877,294.22 | 2,491.00 | 0.0000 | 7.42 | 2,498.44 |
| J-18 | 514,007.40 | 877,161.75 | 2,490.00 | 0.0000 | 10.43 | 2,500.45 |
| J-19 | 513,916.30 | 877,025.32 | 2,492.00 | 0.0000 | 10.63 | 2,502.65 |
| J-20 | 513,851.42 | 876,873.92 | 2,496.00 | 0.0000 | 8.84 | 2,504.86 |
| J-21 | 513,873.08 | 876,830.51 | 2,491.00 | 0.0000 | 14.48 | 2,505.51 |
| J-22 | 513,814.94 | 876,755.76 | 2,492.00 | 0.0000 | 14.75 | 2,506.78 |
| J-23 | 513,772.38 | 876,552.20 | 2,497.00 | 0.0000 | 12.54 | 2,509.56 |
| J-24 | 513,741.60 | 876,477.50 | 2,502.50 | 0.0000 | 8.13 | 2,510.65 |
| J-25 | 513,741.63 | 876,383.12 | 2,503.00 | 0.0000 | 8.90 | 2,511.91 |
| J-26 | 513,743.25 | 876,233.10 | 2,511.12 | 0.0000 | 2.80 | 2,513.92 |
| J-27 | 513,710.78 | 876,126.64 | 2,510.50 | 0.0000 | 4.91 | 2,515.42 |
| J-28 | 513,647.42 | 875,938.47 | 2,510.00 | 0.0000 | 8.06 | 2,518.08 |
| J-29 | 513,617.64 | 875,792.97 | 2,521.00 | 0.0000 | -0.93 | 2,520.07 |
| J-30 | 513,504.98 | 875,568.10 | 2,511.00 | 0.0000 | 12.42 | 2,523.44 |
| J-31 | 513,604.30 | 875,513.77 | 2,507.00 | 0.0000 | 17.93 | 2,524.96 |
| J-32 | 513,745.02 | 875,441.66 | 2,508.00 | 0.0000 | 19.04 | 2,527.08 |
| J-33 | 513,818.34 | 875,363.93 | 2,515.00 | 0.0000 | 13.49 | 2,528.51 |
| J-34 | 514,021.97 | 881,378.97 | 2,279.16 | 0.0000 | -20.36 | 2,258.76 |
| J-35 | 514,013.90 | 881,231.20 | 2,284.08 | 0.0000 | -25.27 | 2,258.76 |
| J-36 | 514,008.55 | 881,143.07 | 2,291.53 | 0.0000 | -32.70 | 2,258.76 |
| J-37 | 513,155.97 | 876,628.80 | 2,438.55 | 0.0000 | 75.97 | 2,514.67 |
| J-38 | 513,119.55 | 876,631.43 | 2,432.81 | 0.0000 | 80.11 | 2,513.08 |
| J-39 | 513,074.61 | 876,657.80 | 2,428.16 | 0.0000 | 82.48 | 2,510.81 |

| | | | | | | |
|---|---|---|---|---|---|---|
| J-40 | 513,047.54 | 876,704.09 | 2,428.41 | 0.0000 | 79.90 | 2,508.47 |
| J-41 | 513,031.56 | 876,833.50 | 2,422.91 | 0.0512 | 79.71 | 2,502.78 |
| J-42 | 513,009.07 | 876,960.01 | 2,407.91 | 0.0667 | 89.14 | 2,497.23 |
| J-43 | 513,213.33 | 877,201.83 | 2,417.94 | 0.1116 | 65.70 | 2,483.78 |
| J-44 | 513,136.44 | 877,108.40 | 2,413.92 | 0.0543 | 74.82 | 2,488.89 |
| J-45 | 513,268.15 | 877,277.01 | 2,409.96 | 0.1923 | 69.83 | 2,479.93 |
| J-46 | 514,255.34 | 875,059.74 | 2,528.94 | 0.0636 | 25.91 | 2,554.90 |
| J-47 | 514,258.11 | 874,985.22 | 2,527.55 | 0.0264 | 27.30 | 2,554.90 |
| J-48 | 513,904.16 | 875,372.26 | 2,515.34 | 0.0000 | 38.02 | 2,553.43 |
| J-49 | 515,511.00 | 878,265.24 | 2,510.00 | 0.0000 | 7.32 | 2,517.34 |
| J-50 | 514,014.10 | 875,316.25 | 2,524.37 | 0.1597 | 29.19 | 2,553.62 |
| J-51 | 514,131.78 | 875,277.71 | 2,536.74 | 0.1085 | 17.93 | 2,554.71 |
| J-52 | 515,836.40 | 879,276.53 | 2,452.54 | 0.0000 | 19.18 | 2,471.75 |
| J-53 | 514,479.12 | 877,887.16 | 2,470.02 | 0.0000 | 63.34 | 2,533.49 |
| J-54 | 514,966.30 | 877,881.42 | 2,469.56 | 0.0000 | 0.12 | 2,469.68 |
| J-55 | 514,994.95 | 877,936.55 | 2,468.88 | 0.1256 | 0.83 | 2,469.71 |
| J-56 | 513,418.79 | 876,610.28 | 2,474.38 | 0.1659 | 51.88 | 2,526.37 |
| J-57 | 514,431.89 | 877,765.25 | 2,473.57 | 0.1706 | 59.81 | 2,533.50 |
| J-58 | 515,808.40 | 879,140.96 | 2,455.52 | 0.0000 | 16.20 | 2,471.75 |
| J-59 | 513,724.78 | 877,004.43 | 2,477.04 | 0.0698 | 64.46 | 2,541.63 |
| J-60 | 514,430.67 | 878,017.65 | 2,469.00 | 0.0000 | 64.34 | 2,533.47 |
| J-61 | 514,327.12 | 877,924.85 | 2,471.58 | 0.0000 | 61.75 | 2,533.45 |
| J-62 | 514,523.07 | 877,411.14 | 2,478.09 | 0.0000 | 55.32 | 2,533.52 |
| J-63 | 514,477.20 | 878,033.34 | 2,469.66 | 0.0000 | 63.68 | 2,533.47 |
| J-64 | 514,820.78 | 877,700.28 | 2,473.72 | 0.2310 | -4.08 | 2,469.64 |
| J-65 | 514,529.35 | 878,011.43 | 2,471.14 | 0.0000 | 62.21 | 2,533.48 |
| J-66 | 513,958.35 | 877,517.02 | 2,475.07 | 0.0000 | 58.17 | 2,533.36 |
| J-67 | 514,911.08 | 877,784.19 | 2,473.63 | 0.1287 | -3.96 | 2,469.66 |
| J-68 | 514,477.26 | 877,528.69 | 2,480.18 | 0.0000 | 53.19 | 2,533.48 |
| J-69 | 513,721.71 | 876,857.97 | 2,480.29 | 0.2217 | 61.32 | 2,541.73 |
| J-70 | 514,519.54 | 877,307.18 | 2,482.79 | 0.0000 | 50.73 | 2,533.62 |
| J-71 | 515,396.71 | 878,764.77 | 2,464.89 | 0.0899 | 5.42 | 2,470.32 |
| J-72 | 514,293.52 | 877,759.70 | 2,478.64 | 0.0000 | 54.69 | 2,533.44 |
| J-73 | 514,309.31 | 877,754.46 | 2,479.23 | 0.1287 | 54.10 | 2,533.44 |
| J-74 | 514,850.48 | 877,679.55 | 2,477.86 | 0.0000 | -8.20 | 2,469.64 |
| J-75 | 515,792.26 | 879,088.09 | 2,462.73 | 0.0899 | 9.01 | 2,471.75 |
| J-76 | 514,446.65 | 877,529.05 | 2,484.05 | 0.1349 | 49.28 | 2,533.43 |
| J-77 | 514,408.66 | 877,528.96 | 2,484.76 | 0.1256 | 48.54 | 2,533.40 |
| J-78 | 514,473.83 | 877,435.01 | 2,484.73 | 0.1085 | 48.67 | 2,533.50 |
| J-79 | 514,521.45 | 877,237.15 | 2,486.13 | 0.0000 | 47.46 | 2,533.68 |
| J-80 | 515,131.25 | 877,971.74 | 2,475.35 | 0.0868 | -5.19 | 2,470.15 |
| J-81 | 514,473.08 | 877,409.14 | 2,485.34 | 0.0605 | 48.07 | 2,533.51 |
| J-82 | 514,384.36 | 877,648.63 | 2,484.07 | 0.2434 | 49.22 | 2,533.39 |
| J-83 | 513,953.57 | 877,418.08 | 2,482.10 | 0.2527 | 51.11 | 2,533.31 |
| J-84 | 515,179.85 | 878,062.74 | 2,475.41 | 0.1442 | -3.81 | 2,471.60 |

| | | | | | | |
|---|---|---|---|---|---|---|
| J-85 | 515,274.46 | 877,900.68 | 2,484.25 | 0.3117 | -14.64 | 2,469.58 |
| J-86 | 515,192.41 | 878,079.18 | 2,475.98 | 0.0000 | -6.19 | 2,469.78 |
| J-87 | 514,319.96 | 877,097.62 | 2,489.00 | 0.0000 | 44.27 | 2,533.36 |
| J-88 | 513,584.76 | 876,572.29 | 2,486.35 | 0.1768 | 47.58 | 2,534.02 |
| J-89 | 514,495.59 | 877,092.72 | 2,489.49 | 0.0000 | 44.24 | 2,533.82 |
| J-90 | 514,943.01 | 877,608.86 | 2,485.43 | 0.2822 | -15.83 | 2,469.57 |
| J-91 | 514,120.84 | 877,646.89 | 2,483.09 | 0.1535 | 50.47 | 2,533.66 |
| J-92 | 514,323.62 | 877,224.42 | 2,489.00 | 0.0000 | 44.27 | 2,533.36 |
| J-93 | 514,504.28 | 877,128.97 | 2,489.83 | 0.0000 | 43.87 | 2,533.78 |
| J-94 | 515,280.78 | 878,354.85 | 2,475.51 | 0.1287 | -4.13 | 2,471.37 |
| J-95 | 514,186.09 | 876,857.51 | 2,489.00 | 0.0295 | 52.87 | 2,541.97 |

| | | |
|---|---|---|
| HYDRAULIC MODELING OF ASELLA WATER SUPPLY DISTRIBUTION NETWORK -BY SHAMBEL BELACHEW.wtg<br>10/6/2020 | Bentley Systems, Inc. Haestad Methods Solution Center<br>27 Siemon Company Drive Suite 200 W<br>Watertown, CT 06795 USA +1 -203-755-1666 | Bentley WaterGEMS V8i (SELECTseries 5)<br>[08.11.05.61]<br>Page 1 of 1 |

The above appendix shows the sample report of nodes at maximum hour consumption computed in Bentley WaterGEMS V8i and the left Report of junction from junction 96 up to 650 is not listed here in order to minimize the page.

## Appendix D: Extended period state Analysis Table for Nodes (Junctions) at minimum hour consumption

Junction FlexTable: Table – 2

**Current Time: 21.000 hours**

| Label | X (m) | Y (m) | Elevation (m) | Demand (L/s) | Pressure (m H2O) | Hydraulic Grade (m) |
|---|---|---|---|---|---|---|
| J-1 | 522,411.35 | 856,827.40 | 2,485.00 | 0.0000 | 82.40 | 2,567.57 |
| J-2 | 514,005.31 | 875,306.89 | 2,524.00 | 0.0000 | 39.21 | 2,563.29 |
| J-3 | 514,131.88 | 875,266.28 | 2,536.00 | 0.0000 | 27.01 | 2,563.06 |
| J-4 | 514,253.49 | 875,379.99 | 2,538.57 | 0.0000 | 23.98 | 2,562.59 |
| J-5 | 514,249.43 | 875,510.42 | 2,538.57 | 0.0000 | 23.75 | 2,562.37 |
| J-6 | 514,253.91 | 875,646.75 | 2,538.57 | 0.0000 | 23.51 | 2,562.13 |
| J-7 | 514,373.65 | 875,683.94 | 2,538.57 | 0.0000 | 23.30 | 2,561.91 |
| J-8 | 514,260.01 | 875,242.69 | 2,535.00 | 0.0000 | 27.78 | 2,562.83 |
| J-9 | 514,478.77 | 878,042.64 | 2,469.00 | 0.0000 | 16.51 | 2,485.55 |
| J-10 | 514,543.21 | 878,015.06 | 2,471.00 | 0.0000 | 15.45 | 2,486.48 |
| J-11 | 514,489.21 | 877,883.28 | 2,470.00 | 0.0000 | 18.33 | 2,488.36 |
| J-12 | 514,440.59 | 877,762.81 | 2,474.00 | 0.0000 | 16.05 | 2,490.09 |
| J-13 | 514,397.02 | 877,645.25 | 2,484.00 | 0.0000 | 7.73 | 2,491.75 |
| J-14 | 514,343.06 | 877,520.10 | 2,493.40 | 0.0000 | 0.15 | 2,493.56 |

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|---|---|---|---|---|---|---|
| J-15 | 514,186.32 | 877,504.69 | 2,493.00 | 0.0000 | 2.64 | 2,495.64 |
| J-16 | 514,131.76 | 877,413.18 | 2,492.00 | 0.0000 | 5.04 | 2,497.05 |
| J-17 | 514,077.69 | 877,294.22 | 2,491.00 | 0.0000 | 7.77 | 2,498.79 |
| J-18 | 514,007.40 | 877,161.75 | 2,490.00 | 0.0000 | 10.75 | 2,500.77 |
| J-19 | 513,916.30 | 877,025.32 | 2,492.00 | 0.0000 | 10.93 | 2,502.95 |
| J-20 | 513,851.42 | 876,873.92 | 2,496.00 | 0.0000 | 9.11 | 2,505.13 |
| J-21 | 513,873.08 | 876,830.51 | 2,491.00 | 0.0000 | 14.75 | 2,505.78 |
| J-22 | 513,814.94 | 876,755.76 | 2,492.00 | 0.0000 | 15.00 | 2,507.03 |
| J-23 | 513,772.38 | 876,552.20 | 2,497.00 | 0.0000 | 12.76 | 2,509.79 |
| J-24 | 513,741.60 | 876,477.50 | 2,502.50 | 0.0000 | 8.34 | 2,510.86 |
| J-25 | 513,741.63 | 876,383.12 | 2,503.00 | 0.0000 | 9.09 | 2,512.11 |
| J-26 | 513,743.25 | 876,233.10 | 2,511.12 | 0.0000 | 2.97 | 2,514.10 |
| J-27 | 513,710.78 | 876,126.64 | 2,510.50 | 0.0000 | 5.06 | 2,515.57 |
| J-28 | 513,647.42 | 875,938.47 | 2,510.00 | 0.0000 | 8.19 | 2,518.20 |
| J-29 | 513,617.64 | 875,792.97 | 2,521.00 | 0.0000 | -0.82 | 2,520.17 |
| J-30 | 513,504.98 | 875,568.10 | 2,511.00 | 0.0000 | 12.48 | 2,523.51 |
| J-31 | 513,604.30 | 875,513.77 | 2,507.00 | 0.0000 | 17.97 | 2,525.01 |
| J-32 | 513,745.02 | 875,441.66 | 2,508.00 | 0.0000 | 19.07 | 2,527.10 |
| J-33 | 513,818.34 | 875,363.93 | 2,515.00 | 0.0000 | 13.49 | 2,528.52 |
| J-34 | 514,021.97 | 881,378.97 | 2,279.16 | 0.0000 | 95.77 | 2,375.12 |
| J-35 | 514,013.90 | 881,231.20 | 2,284.08 | 0.0000 | 90.86 | 2,375.12 |
| J-36 | 514,008.55 | 881,143.07 | 2,291.53 | 0.0000 | 83.43 | 2,375.12 |
| J-37 | 513,155.97 | 876,628.80 | 2,438.55 | 0.0000 | 81.03 | 2,519.74 |
| J-38 | 513,119.55 | 876,631.43 | 2,432.81 | 0.0000 | 85.07 | 2,518.05 |
| J-39 | 513,074.61 | 876,657.80 | 2,428.16 | 0.0000 | 87.29 | 2,515.63 |
| J-40 | 513,047.54 | 876,704.09 | 2,428.41 | 0.0000 | 84.56 | 2,513.14 |
| J-41 | 513,031.56 | 876,833.50 | 2,422.91 | 0.0177 | 84.00 | 2,507.08 |
| J-42 | 513,009.07 | 876,960.01 | 2,407.91 | 0.0230 | 93.03 | 2,501.13 |
| J-43 | 513,213.33 | 877,201.83 | 2,417.94 | 0.0385 | 68.48 | 2,486.55 |
| J-44 | 513,136.44 | 877,108.40 | 2,413.92 | 0.0187 | 78.04 | 2,492.11 |
| J-45 | 513,268.15 | 877,277.01 | 2,409.96 | 0.0663 | 72.20 | 2,482.31 |
| J-46 | 514,255.34 | 875,059.74 | 2,528.94 | 0.0219 | 28.81 | 2,557.80 |
| J-47 | 514,258.11 | 874,985.22 | 2,527.55 | 0.0091 | 30.19 | 2,557.80 |
| J-48 | 513,904.16 | 875,372.26 | 2,515.34 | 0.0000 | 41.36 | 2,556.79 |
| J-49 | 515,511.00 | 878,265.24 | 2,510.00 | 0.0000 | 16.98 | 2,527.01 |
| J-50 | 514,014.10 | 875,316.25 | 2,524.37 | 0.0551 | 32.48 | 2,556.92 |
| J-51 | 514,131.78 | 875,277.71 | 2,536.74 | 0.0375 | 20.89 | 2,557.67 |
| J-52 | 515,836.40 | 879,276.53 | 2,452.54 | 0.0000 | 21.98 | 2,474.57 |
| J-53 | 514,479.12 | 877,887.16 | 2,470.02 | 0.0000 | 73.50 | 2,543.67 |
| J-54 | 514,966.30 | 877,881.42 | 2,469.56 | 0.0000 | 1.42 | 2,470.98 |
| J-55 | 514,994.95 | 877,936.55 | 2,468.88 | 0.0433 | 2.17 | 2,471.05 |
| J-56 | 513,418.79 | 876,610.28 | 2,474.38 | 0.0572 | 57.71 | 2,532.20 |
| J-57 | 514,431.89 | 877,765.25 | 2,473.57 | 0.0589 | 69.96 | 2,543.67 |
| J-58 | 515,808.40 | 879,140.96 | 2,455.52 | 0.0000 | 19.01 | 2,474.57 |

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|---|---:|---:|---:|---:|---:|---:|
| J-59 | 513,724.78 | 877,004.43 | 2,477.04 | 0.0241 | 71.14 | 2,548.32 |
| J-60 | 514,430.67 | 878,017.65 | 2,469.00 | 0.0000 | 74.52 | 2,543.67 |
| J-61 | 514,327.12 | 877,924.85 | 2,471.58 | 0.0000 | 71.94 | 2,543.67 |
| J-62 | 514,523.07 | 877,411.14 | 2,478.09 | 0.0000 | 65.45 | 2,543.67 |
| J-63 | 514,477.20 | 878,033.34 | 2,469.66 | 0.0000 | 73.86 | 2,543.67 |
| J-64 | 514,820.78 | 877,700.28 | 2,473.72 | 0.0797 | -2.80 | 2,470.91 |
| J-65 | 514,529.35 | 878,011.43 | 2,471.14 | 0.0000 | 72.38 | 2,543.67 |

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| HYDRAULIC MODELING OF ASELLA WATER SUPPLY DISTRIBUTION NET WORK -BY SHAMBEL BELACHEW.wtg<br>10/6/2020 | Bentley Systems, Inc. Haestad Methods Solution Center<br>27 Siemon Company Drive Suite 200 W<br>Watertown, CT 06795 USA +1-203-755-1666 | Bentley WaterGEMS V8i ( SELECTseries 5)<br>[08.11.05.61]<br>Page 1 of 1 |

The above appendix shows the sample report of nodes at minimum hour consumption computed in Bentley WaterGEMS V8i and the left Report of junction from junction 66 up to 650 is not listed here in order to minimize the page.

**Appendix E: Extended period state Analysis Table for pipe (links) at maximum consumption hours**

Pipe Flex Table: Table - 3
**Current Time: 14.000 hours**

| Label | Start Node | Stop Node | Length (m) | Diameter (mm) | Material | Hazen-Williams C | Velocity (m/s) | Headloss Gradient (m/km) |
|---|---|---|---:|---:|---|---:|---:|---:|
| p-1 | J-567 | J-556 | 129 | 100.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-2 | J-556 | J-544 | 124 | 100.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-3 | J-544 | J-524 | 178 | 150.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-4 | J-524 | J-534 | 105 | 150.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-5 | J-534 | J-537 | 111 | 150.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-6 | J-432 | J-433 | 47 | 100.0 | PVC | 150.0 | 0.01 | 0.003 |
| p-7 | J-433 | J-417 | 177 | 150.0 | PVC | 150.0 | 0.01 | 0.000 |
| p-8 | J-537 | J-503 | 186 | 150.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-9 | J-503 | J-465 | 165 | 150.0 | PVC | 150.0 | 0.01 | 0.003 |
| p-10 | J-465 | J-417 | 214 | 150.0 | PVC | 150.0 | 0.01 | 0.000 |
| p-11 | J-503 | J-431 | 168 | 150.0 | PVC | 150.0 | 0.04 | 0.018 |
| p-12 | J-431 | J-442 | 64 | 150.0 | PVC | 150.0 | 0.04 | 0.016 |
| p-13 | J-442 | J-476 | 55 | 150.0 | PVC | 150.0 | 0.04 | 0.019 |
| p-14 | J-476 | J-483 | 75 | 150.0 | PVC | 150.0 | 0.04 | 0.016 |
| p-15 | J-483 | J-426 | 237 | 80.0 | PVC | 150.0 | 0.23 | 0.772 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| p-16 | J-426 | J-409 | 165 | 80.0 | PVC | 150.0 | 0.17 | 0.470 |
| p-17 | J-393 | J-396 | 66 | 50.0 | PVC | 150.0 | 0.14 | 0.533 |
| p-18 | J-396 | J-398 | 48 | 50.0 | PVC | 150.0 | 0.37 | 3.284 |
| p-19 | J-398 | J-401 | 41 | 100.0 | Ductile Iron | 130.0 | 0.14 | 0.316 |
| p-20 | J-401 | J-410 | 59 | 100.0 | Ductile Iron | 130.0 | 0.15 | 0.360 |
| p-21 | J-409 | J-411 | 17 | 50.0 | PVC | 150.0 | 0.12 | 0.437 |
| p-22 | J-411 | J-410 | 170 | 50.0 | PVC | 150.0 | 0.04 | 0.046 |
| p-23 | J-410 | J-404 | 47 | 50.0 | PVC | 150.0 | 0.17 | 0.800 |
| p-24 | J-404 | J-403 | 9 | 50.0 | PVC | 150.0 | 0.17 | 0.794 |
| p-25 | J-403 | J-402 | 10 | 50.0 | PVC | 150.0 | 0.17 | 0.794 |
| p-26 | J-402 | J-406 | 105 | 50.0 | PVC | 150.0 | 0.17 | 0.801 |
| p-27 | J-406 | J-408 | 28 | 50.0 | PVC | 150.0 | 0.17 | 0.797 |
| p-28 | J-408 | J-407 | 26 | 50.0 | PVC | 150.0 | 0.17 | 0.799 |
| p-29 | J-407 | J-405 | 71 | 50.0 | PVC | 150.0 | 0.17 | 0.800 |
| p-30 | J-405 | J-399 | 71 | 50.0 | PVC | 150.0 | 0.17 | 0.800 |
| p-31 | J-399 | J-400 | 94 | 50.0 | PVC | 150.0 | 0.17 | 0.801 |
| p-32 | J-400 | J-395 | 116 | 50.0 | PVC | 150.0 | 0.08 | 0.180 |
| p-33 | J-395 | J-394 | 21 | 50.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-34 | J-413 | J-415 | 156 | 50.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-35 | J-415 | J-421 | 154 | 50.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-36 | J-421 | J-424 | 22 | 50.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-37 | J-424 | J-425 | 14 | 80.0 | PVC | 150.0 | 0.00 | 0.000 |
| p-38 | J-425 | J-435 | 62 | 80.0 | Ductile Iron | 130.0 | 0.00 | 0.000 |
| p-39 | J-435 | J-436 | 62 | 80.0 | Ductile Iron | 130.0 | 0.00 | 0.000 |
| p-40 | J-436 | J-438 | 13 | 80.0 | Ductile Iron | 130.0 | 0.00 | 0.000 |
| p-41 | J-438 | J-441 | 42 | 80.0 | Ductile Iron | 130.0 | 0.00 | 0.000 |
| p-42 | J-441 | J-422 | 144 | 100.0 | Ductile Iron | 130.0 | 0.20 | 0.630 |
| p-43 | J-422 | J-410 | 172 | 100.0 | Ductile Iron | 130.0 | 0.20 | 0.630 |
| p-44 | J-441 | J-447 | 52 | 100.0 | Ductile Iron | 130.0 | 0.20 | 0.629 |
| p-45 | J-447 | J-454 | 123 | 100.0 | Ductile Iron | 130.0 | 0.14 | 0.317 |
| p-46 | J-454 | J-480 | 122 | 100.0 | Ductile Iron | 130.0 | 0.14 | 0.317 |
| p-47 | J-480 | J-497 | 49 | 100.0 | Ductile Iron | 130.0 | 0.15 | 0.356 |
| p-48 | J-497 | J-513 | 48 | 100.0 | Ductile Iron | 130.0 | 0.15 | 0.356 |
| p-49 | J-513 | J-512 | 101 | 100.0 | PVC | 150.0 | 0.17 | 0.371 |
| p-50 | J-512 | J-514 | 146 | 100.0 | PVC | 150.0 | 0.16 | 0.303 |
| p-51 | J-514 | J-508 | 41 | 100.0 | PVC | 150.0 | 0.11 | 0.141 |
| p-52 | J-508 | J-501 | 33 | 100.0 | PVC | 150.0 | 0.10 | 0.126 |
| p-53 | J-501 | J-490 | 58 | 100.0 | PVC | 150.0 | 0.09 | 0.108 |
| p-54 | J-490 | J-457 | 59 | 100.0 | PVC | 150.0 | 0.08 | 0.094 |
| p-55 | J-457 | J-452 | 27 | 100.0 | PVC | 150.0 | 0.08 | 0.095 |
| p-56 | J-452 | J-445 | 48 | 100.0 | PVC | 150.0 | 0.07 | 0.066 |
| p-57 | J-445 | J-447 | 51 | 100.0 | PVC | 150.0 | 0.07 | 0.064 |
| p-58 | J-514 | J-511 | 108 | 150.0 | PVC | 150.0 | 0.04 | 0.014 |
| p-59 | J-511 | J-483 | 115 | 150.0 | PVC | 150.0 | 0.03 | 0.008 |
| p-60 | J-513 | J-506 | 92 | 150.0 | PVC | 150.0 | 0.12 | 0.119 |

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|---|---|---|---|---|---|---|---|---|
| p-61 | J-506 | J-491 | 32 | 150.0 | Ductile Iron | 130.0 | 0.13 | 0.173 |
| p-62 | J-491 | J-516 | 113 | 150.0 | PVC | 150.0 | 0.14 | 0.159 |
| p-63 | J-516 | J-489 | 110 | 150.0 | PVC | 150.0 | 0.16 | 0.186 |
| p-64 | J-489 | J-470 | 45 | 150.0 | Ductile Iron | 130.0 | 0.17 | 0.285 |
| p-65 | J-470 | J-458 | 45 | 150.0 | Ductile Iron | 130.0 | 0.17 | 0.292 |

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| HYDRAULIC MODELING OF ASELLA WATER<br>SUPPLY DISTRIBUTION NETWORK -BY SHAMBEL BELACHEW.wtg<br>10/6/2020 | Bentley Systems, Inc. Haestad Methods Solution Center<br>27 Siemon Company Drive Suite 200 W<br>Watertown, CT 06795 USA<br>+1-203-755-1666 | Bentley WaterGEMS V8i (SELECTseries 5)<br>[08.11.05.61]<br>Page 1 of 1 |

The above appendix shows the sample report of pipe at maximum hour consumption computed in Bentley WaterGEMS V8i and the left Report of pipe from junction 65 up to 724 is not listed here in order to minimize the page.