**JIMMA UNIVERSITY**

**JIMMA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF GRADUATE STUDIES**

**FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**ENVIRONMENTAL ENGINEERING MSC PROGRAMME**

# EVALUATION OF WATER TREATMENT PLANT AND DISTRIBUTION NETWORK PERFORMANCE OF NAQAMTE TOWN, OROMIYA, ETHIOPIA

**BY: NAGARO TUGE**

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN ENVIRONMENTAL ENGINEERING.**

**FEBRUARY, 2020**

**JIMMA, ETHIOPIA**

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**FEBRUARY, 2020**

**JIMMA, ETHIOPIA**

## DECLARATION

This thesis entitled "Evaluation of water treatment plant and distribution network performance of Naqamte town, Oromiya, Ethiopia" has not been presented for a master or any other degree in Jimma Institute of Technology (JIT) or in any other university.

I have identified all material in this thesis which is not my own work through appropriate referencing and acknowledgement.

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| Nagaro Tuge | ________________ | ________________ |
| Candidate | Signature | Date |

This thesis has been submitted for examination with my approval as a university supervisor

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**ACKNOWLEDGEMENT**

First of all, I praise Almighty God for providing me with good health, wisdom and strength throughout my duty and help me to complete this study. For most, I would like to express my sincere gratitude to my main advisor, Dr. Ing. Fekadu Fufa and co-advisor Mr. Desalegn Geleta for the enthusiasm and immense knowledge, their guidance helped me in all the time writing of my thesis, their extend support and guiding me on the right direction to accomplish this work successfully.

I have advantageous a lot from DH consultant, and Naqamte town water supply service office; therefore I would like to thank all the staff members of the organizations for their willingness to use all the required data without any payment. I would like to express a great gratitude to Ms. Mulunesh Bekele (manager of Naqamte town water service office) and Mr. Shibiru Tadele (Water quality expert of the town) for their helps me to get all the detail information and data related with the subject matter.

I would like to thank Mr. Lalisa Likessa (manager of water supply sanitation, funded by World Bank) for his helpful and voluntary to get pressure gauge instrument during field data observation and also his effort by giving me a plenty of time in helping almost all the necessary data and information, especially in case of water treatment plant of the town. At last but not least, I would like to express my deepest gratitude to my brother for his moral supports and motivations until the end of this work.

## ABSTRACT

*In many developing countries including Ethiopia water supply system has the problem of hydraulic performance, water loss or leakage is the growing concern. Additionally, Disinfection By-Product is another problem available in water treatment and distribution system. The objective of this study was evaluating the performance of Naqamte town water distribution networks and treatment plant. Hence, during this study, hydraulic performance, water loss in water distribution system, disinfection and disinfection by-product was addressed. To evaluate the hydraulic performance of the water distribution network, WaterGEMs V8i was adopted for water distribution modeling and for water treatment plant simulation WatPro 4.0 software was applied for disinfection and treatment plant performance. This study requires some tools, Geographical Position System and pressure gauge meter that was used to collect the required elevation data, while Microsoft Excel sheet was also used in organizing elevation data, and ArcGIS 10.3 was used to display the overlapped shape file of the distribution network on the topographic map of the town. The study was involved both primary and secondary data, the primary data was received from field surveying (pressure reading and elevation). While the secondary data was collected from different newspaper, journals, related books, literature reviews, design report, the town water supply service office existing documents and annual. As per the analyzed results; the current maximum water demand in Naqamte town is estimated at 12,345.36* $m^3$*/day, while small reservoirs capacity and low raw water pump efficiency were observed in the town water distribution networks. As per the discussion held with the Naqamte water supply and sewerage authority and field visit, the major factors of water loss was identified. As per the calculation result; the treatment plant efficiency of the town was estimated as 69.75%. In case of giardia and viruses reduction (22.6% and 75.34%), i.e. the results obtained from the treatment plant simulation did not obey the surface water treatment rule. Despite its small amount; disinfection by products has been found in the town's water treatment plant. As per the calculation obtained; the contact time of the water system did not met the contact time requirement because 0.476<1. In general, the current water distribution network and treatment plant of Naqamte town was in poor performance and were not conducted adequate water to the various demand categories of the town. Hence, it is important to rehabilitate and improve the water distribution network and treatment plant of the town in order to fulfill the required need.*



*KEY WORDS:* ***Hydraulic performance, Water distribution network, Water Gems, WatPro.***

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## ACRONMYS

| | |
|---|---|
| ArcGIS | Arc Geographical Information System |
| CSA | Central Statistics Agency |
| CT | Contact Time |
| DH | Desta Horecha consultant |
| DBPs | Disinfection By-Products |
| EPA | Environmental Protection Agency |
| EEPCO | Ethiopian Electric Power Corporation |
| EWWCE | Ethiopian Water Work Construction Enterprise |
| GPS | Global Positioning System |
| IWS | Intermittent Water Supply |
| IWA | International Water Association |
| JIT | Jimma Institute of Technology |
| m.a.s.l. | meter above sea level |
| MoWR | Ministry of Water Resources |
| NTWSSO | Naqamte Town Water Supply Service Office |
| NWTP | Naqamte Water Treatment Plant |
| OWWCE | Oromiya Water Work Construction Enterprise |
| PVC | Polyvinyl Chlorine |
| PRV | Pressure Reducing Valve |
| PLC | Private Limited Company |
| SWTR | Surface Water Treatment Rule |
| TSU | Traditional Source Users |
| UFW | Unaccounted For Water |
| WDNs | Water Distribution Networks |
| WTP | Water Treatment Plant |
| WUAM | Water Utility Asset Management |
| WHO | World Health Organization |

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background

Water is the most precious gift of nature and one of the basic source of prosperity which supports life. Accordingly, NRC, (2006); explained that it is not exaggerates to say that supplying and distributing of adequate water from the foundation of contemporary life.

As per Kochhar, *et al*., (2015); problem of water is growing as global concern and that has an impact on countries' economic prospects and also rising water stress, large supply variability, and lack of access to safe and adequate drinking water are a frequent problems in many parts of the world. Especially, developing countries face greater challenges of adequate water distribution because of their larger population growth rate, poor infrastructure, lower income levels, and less developed policy and institutional capacity

Some water distribution system across the country used beyond their expected life span which deteriorates performance of water distribution network. Accordingly, Grady, *et al*., (2014); suggested that in developing countries; one of the commonly cited constraints to effective water provisioning is the "aging infrastructure" problem. And these were presents many technical limitations for effective and continues water distribution system to customers.

The problems of with access to sufficient water are mostly happen in the developing world, and more than one billion people were suffer without access to water for their basic needs. Thereby, the United Nations Millennium Declaration and the plan of implementation of the world; was set reducing the proportion of people having without adequate access to water by one-half for the year 2015. Hence, adequate water distribution is one of the international goals for sustainable development (Renwick, 2013).

According to the Global Water Supply and Sanitation Assessment 2000 Report, the African capital cities are having 43% house connection or yard tap, 21% served by public tap while 31% of the population are un-served (WHO, 2000).

To sustain their daily life every citizen in the country has the right to have access to potable water. Thereby, Seifu, (2012); forwarded that access to safe drinking water supplies and sanitation services in Ethiopia are among the lowest in Sub-Saharan.

According to Benyam, (2016); managing and reducing losses of water at all levels of a distribution system remains one of the major challenges facing many water utilities in most developing countries including Ethiopia and 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. Accordingly, Lambert, (1994); explained that loss of treated water occurs by leakages and overflows from the pressurized pipes and fittings in water undertaker distribution systems and customers' private supply pipes and water loss via leakage is acknowledged as one of the primary challenges facing water distribution system operations.

Eldien, *et al.*, (2017); showed that design of water treatment plants, the provision of safe water is the prime goal. Water treatment plants have demonstrated the ability to produce safe water under adverse conditions and they must also produce water which is appealing to the consumer. Ideally, appealing water is one that is clear and colorless, pleasant to the taste, and cool. It is non-staining, and is neither corrosive nor scale forming. Thereby, disinfection of raw water plays an important role in drinking water treatment because it kills a lot of organic matters that have a capable of causing disease which is harmful to human health. One of the most disinfectants is chlorine which is used in drinking water treatment process because of its low cost or inexpensive and omits huge amount of pathogens.

According to Ahammed and Melchers, (1997); water distribution systems consist of pipeline networks and associated components, most of which is underground and exposed to soil corrosion and mechanical stress from the surrounding soil, surface traffic, and internal water pressure and pipe failure in water distribution systems disrupts the water supply to consumers and reduces the reliability of the system. Accordingly, Babovic, *et al.*, (2002); about 35% to 60% of the supplied volume is wasted due to pipe leakages. Thereby, inspection, control and planned maintenance and rehabilitation programs are necessary to properly operate existing water distributions systems (Saegrov *et al*, 1999).

Now a day, it is the tangible fact that Naqamte town population are suffering from the scarcity of water supply because of the fast growing population in the town. Hence, the water supply for the town is not balanced with this fast growing people so that the costumers are not satisfied since they are challenging with intermittent water supply. Thus, such problem may be raised due to different factors; namely, poor performance of water distribution system, failure of distribution network, improper design of water treatment plant and distribution train, burst of the pipe that causes water loss and the like.

In general, evaluating water treatment is the prime goal of the water treatment plant that results a lot of positive attitude for users in case of gaining safe drinking water and water distribution network is the system that conveys the treated water to the consumers. These two issues are the pillar for safe drinking water which interdependent to each other. However, there are a lot of problems that suffers the performance of water distribution network. For instance, water loss or leakage is one of the great headaches for water distribution and leads the water system to intermittent water supply. Hence, Naqamte town water distribution system faces intermittent water supply due the problem mentioned above.

## 1.2 Statement of the problem

The main problem for providing sufficient water supply to the rapidly growing population (developing countries) is increasing from time to time which leads to intermittent water supply system. This can be occurred due to poor hydraulic performance of water distribution network. In many Ethiopian urban areas including Naqamte town majority of householders consume their total water needs from the town’s water supply system either directly through private connections or public taps. According to Naqamte town water supply service office reports, “existing water supply system has served beyond its design period and currently there is the problem of intermittent water distribution in the town”.

Naqamte town’s water distribution system faces numerous conditions that could lead to a failure (natural or man-made) disruptions. Accordingly, Wu, *et al*., (2010); suggested that not all water produced reaches the customers to generate revenue for water companies. Instead, a significant portion of it is lost, due to leakage from water mains and unauthorized water use.

The failure of water infrastructure may cause water loss in the distribution system, and additionally there are a lot of factors that causes water loss (age, size of pipes, metering inaccuracies, and man-made and animal disruptions).

Hence, the level of water loss in towns' water distribution system depends not only on aging of the infrastructure, but also the skilled man power, quality of material used, and customers' awareness and attitude towards water.

Hence, not only the government body but also the individual have a tremendous role to control the water loss and the effect of intermittent water supply. The other Observed problem in Naqamte town is frequent pipe bursting in the water distribution network during which the town water utility does not have immediate response for maintenance. Hence, frequent supervision pipe is required to overcome water loss through pipe bursting.

The loss of treated water occurs by leakages and overflows from the pressurized pipes and fittings in water undertaker distribution systems and customers' private supply pipes (Lambert, 1994). Poor performed water treatment plant of the town is also another problem observed during which the town water utility does not take urgent action for the problem in order to provide safe drinking water for customers. This poor performance can be described in terms of using chlorine as a disinfectant. It has a chance to form Disinfection By-Products so that as alternative using chlorine dioxide as disinfectant is important because it does not form DBPs. (For this reasons, this study was primed to address the current performance of Naqamte town existing water treatment and distribution network).

## 1.3 Objectives

### 1.3.1 General Objective

The general objective of this study is to evaluate water treatment plant and distribution network performance and give awareness for municipal officials of Naqamte town to a better evaluation of the future water supply system in the town.

### 1.3.2 Specific objectives

- To evaluate the hydraulic performance of water distribution network;
- To evaluate the efficiency of water treatment plant and,
- To identify the main factors of water loss in distribution system.

## 1.4 Research questions

1. How to evaluate the hydraulic performance of water distribution network?
2. How to evaluate the efficiency of water treatment plant?
3. What are the main factors of water loss in the town water supply system?

## 1.5 Justification of the study

Provision of treated and adequate water supply services is necessary components for sustainable development. Hence, water treatment plant has to be evaluated to make the drinking water safe from unwanted disease causing organisms (pathogens). The disinfection of raw water plays an important role in drinking water treatment because it kills a lot of organic matters. In addition, Water distribution networks (WDNs), are complex interconnected networks consisting of sources, pipes, and other hydraulic control elements such as pumps, valves, regulators and tanks are requires extensive planning and maintenance to ensure good quality water is delivered to all customers (Shinstine, *et al*., 2002). The great problem of water distribution system is water loss that obstacles the deliverance of water to the costumers as necessary as possible.

Therefore, evaluating the performance of water treatment and distribution network is very important thing in order to deliver safe drinking water to costumers, so that Naqamte town population can be benefited from this study in the case of their water distribution system, for this reason this study is conducting.

## 1.6 Scope of the study

This study is geographically limited to Naqamte town water supply system; water treatment plant and distribution network. Thereby, the study mainly focused on the evaluation of hydraulic performance of water distribution network, evaluation of water treatment plant, identifying the major factors of water loss in distribution system. This was achieved with hydraulic modeling (WaterGEMS V8i software) and water treatment simulation (WatPro 4.0 software i.e. mainly focuses on evaluation of water treatment plant, especially focuses on disinfection by-product), and made of discussion with the town water utility personnel in order to collect the necessary information in the study area.

In general, the study work was limited to evaluate the performance of water treatment and distribution network (from clear water to distribution end point) of Naqamte town water supply system in western Oromiya region of Ethiopia.

## 1.7 Significance of the study

The quality of being important of this study was to evaluate the hydraulic performance of water distribution network, evaluating the performance of water treatment and identifying the major factors of water loss. Hence, it solves the problem of intermittent water supply system by identifying the major factors that facilitates water loss or leakage; this ensures sustainability of water supply to the town.

Besides of evaluating the performance of water distribution network, it is inevitable that to check out the performance of water treatment plant of the town whether it is safe to drink or not. The study will also make the water supply service office beneficiary in planning the future of water distribution system for the better evaluation and efficiency improvement. The up-coming authors may uses this research for their findings.

Water distribution systems are designed to adequately satisfy the water requirements for a combination of domestic, commercial, industrial, and firefighting purposes. The system should be capable of meeting the demands placed on it at all times and at satisfactory hydraulic performance. It should enable reliable operation during irregular situations and perform adequately under varying demand loads. Model building is taking place by compiling from different data sources. So that WaterGEMS is responsible in model management and hydraulic analysis and Wapro is for water treatment plant simulation. As a result, results are carefully analyzed and compared with the standard design criterions. The system is also, evaluated for different operation conditions. Therefore, this study could be a significant input for NWSSO to reconsider their system and take any necessary measures during upgrading & rehabilitation of the system.

## 1.8 Limitation of the study

The availability and the accessibility of quality data was the main limitation of the study. Since the project was constructed many years ago, some of the compiled data were not available.

For the simulation of water treatment plant the data which needs to be measured (for DBPs) was not accomplished due to the lack of instrument for calibration purposes. Moreover, the political situation of the town was not convenient enough, especially for gathering data by field observation. Pressure calibration and validation work was not held for the low demand time (night time) since the town is under command post it is such difficult to move freely within the town after 12:30 hr (L.T). Generally, political situation of the town was the most significant factor for the limitation of this study.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 General

Water is a valuable resource, critical to economic development (Horne, 2013). However, developing countries worldwide face significant challenges in managing increasing demand for urban water because of industrialization, urbanization and the potential impacts of global warming on freshwater supply (Araral & Wang, 2013). Moreover, not all water produced reaches the customers to generate revenue for water companies. Instead, a significant portion of it is lost, due to leakage from water mains and unauthorized water use (Wu, *et al*., 2010). In spite of the above fact not only developing but also developed countries can face significant challenges in managing increasing demand for urban water but the level of challenges may be low to some extent.

Jarrar H, (1998); studied the hydraulic performance of water distribution systems under the action of cyclic pumping; the results show that the network under consideration is exposed to relatively high-pressure values throughout. The velocity of the water through the network attained also high values. These high values of pressure and velocity have negative effects on the performance of the network.

Water distribution networks (WDNs) are complex interconnected networks consisting of sources, pipes, and other hydraulic control elements such as pumps, valves, regulators, tanks etc., that require extensive planning and maintenance to ensure good quality water is delivered to all customers (Shinstine, *et al.,* 2002). These networks are often described in terms of a graph, with links representing the pipes, and nodes representing connections between pipes, hydraulic control elements, consumers, and sources (Ostfeld *et al.,* 2002). They are vital part of urban infrastructure and require high investment, operation and maintenance costs.

In developing countries; many water authorities are facing the challenges in providing adequate water supply to the rapidly growing populations'. Thereby, most of the existing water supply systems are unable to meet the various demands of water.

Beside to this; infrastructural aging problem, poor management of the existing system components/assets and utilities capacity shortages were increases the level of water losses in the distribution system (Welday, 2005; Jalal, 2008 and Benyam, 2016).

Despite to the above mentioned fact rarely the issue is inevitable in the developed country because of minor factors like poor management of the system. Perez, Martinez and Vela (1993); suggested that a method for optimal design by considering factors other than pipe size. Pressure reducing valves were suggested to reduce the pressure in the downstream pipes.

According to EPA, (2011); treatment of source water removes contaminants that are unhealthy or undesirable for consumption. The type of treatment operation performed at a drinking water treatment plant (WTP) and treatment chemicals used depend on the contaminants present in the source water. The removed contaminants and treatment chemical composition impact the content and quantity of residuals generated.

Several disinfection methods are used in water treatment. Disinfection with chlorine is the most widely used method for large water supplies but its application is less common in small supplies. After water is treated, it is inevitable that water distribution network conveys the treated water to consumers. Safe or treated water is the most crucial thing in the health quality of the society.

As per Giustolisi, *et al*., (2008); the consideration of water loss over time as systems age, physical networks grow, and consumption patterns mature should be an integral part of effective asset management. For this, the use of planning and management tools for water management in urban environments became a promising area of study (Tabesh *et al*., 2014). Additionally, poor management of the existing infrastructural asset increases the level of water loss in water supply.

Leakage is usually the major the components of water loss in developed countries, but this is not always the cause in developing or partially developed countries, where illegal connections, meter error, or an accounting error are often more significant ( Welday, 2005., Farley and Trow, 2003).

Vairavamoorthy and Lumbrs, (1998); studied that the leakage reduction in water distribution systems depending on optimal valve control. The inclusion of pressure- dependent leakage terms in network analysis allows the application of formal optimization techniques to identify the most effective means of reducing water losses in distribution systems. They describe the development of an optimization method to minimize leakage in water distribution systems through the most effective settings of flow reduction valves.

In general, using a computer model; assessing the hydraulic behaviors and evaluating the performance of existing towns' water distribution network is advantageous.

Therefore, 'making hydraulic simulation software, especially from hydraulic point view using engineering approach is one of the method used for discussion and decision measure on the system, either is the system within level of service based on pressure consideration or not' (Hussni & Zyoud, 2003).

## 2.2 Types of water distribution system

According to Adeosun O, (2014); the water distribution networks are classified and explained as below;

### 2.2.1 Branched system

This network is also called a tree system. The water has only one possible path from the source to a customer. Thereby, these are applicable for small-capacity water suppliers, and are common in most developing countries. The advantage of this system is the most economical because of its low cost, but it has some disadvantages as presented below; Low reliability, affects all users especially located downstream of any breakdown in the system. So that, the water services were interrupted until the repairs are finished, Fluctuating in water demand, producing rather large pressure variations in the system, when there is a need for developing the network, new branches follow that development and new dead ends will be constructed.

### 2.2.2 Looped system

As the name suggests, in looped systems it serves different paths that water can follow to get from the source to a particular customer.

The systems are generally more desirable than branched systems because it coupled with sufficient valves and accessories, and can provide reliability in the water distribution. In these systems because of more than one path for water, the system capacity is greater and it improves the hydraulics of the distribution system. In the looped system, the break pipe can be isolated and repaired with little impact on customers outside of that immediate area. While, the effect of water service interruption is more significant to branched system.

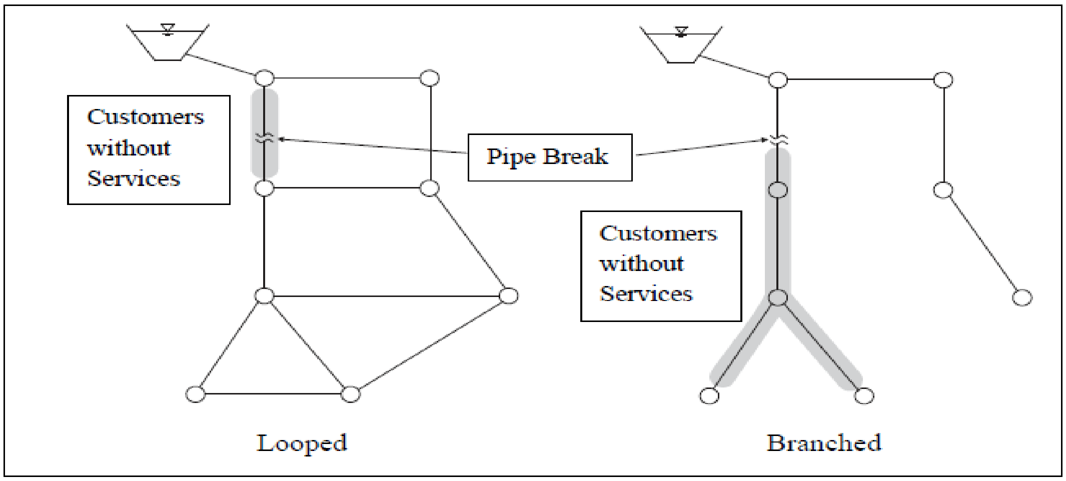


Figure 2.1: Looped and branched networks after network failure (Source: Adeosun O, 2014)

### 2.2.3 Ring systems

The mains form a ring around the area under service, secondary pipes connecting the mains and delivering the water to the consumers. The supply main is laid all along the peripheral roads and sub mains branch out from the mains. This system also follows the grid iron system with the flow pattern in character to that of dead end system. So that determination of the size of pipes is easy. Its advantage is that water is kept in good circulation due to the absence of dead ends and its disadvantage is exact calculation of size of pipes is not possible due to provision of valves on all branches.

### 2.2.4 Radial systems

The area under service in the radial system is divided into subareas, and a storage tank is placed in the center of each subarea to supply. The supply pipes are laid radially ending towards the periphery. It gives quick services, the initial cost is low, has a maintenance low and calculation of pipe sizes is easy. The end of distributor near to the substation gets heavily loaded.

## 2.3 Components of water distribution network

### 2.3.1 Transmission and distribution mains

In the water distribution system, piping system is often categorized as transmission/trunk mains and distribution mains (Tomas, *et al.*, 2003);

#### 2.3.1.1 Transmission mains

Transmission mains were consist of components that are convey large amounts of water over great distances, typically between major facilities within the distribution system.

In most water supply system, transmission main are mainly used to transport water from treatment plant to service reservoirs/ storage tanks. Whereby, individual customers are usually not served from these mains.

#### 2.3.1.2 Distribution mains

Distribution mains are an intermediate pipeline used to delivering water from transmission main to customers. The mains are smaller in diameter than transmission mains, and typically follow the general topology and alignment of the town streets. Different fittings such as elbows, tees, reducers, crosses and numerous other accessories are used in the main to connect pipes. While, other maintenance and operational appurtenances, such as fire hydrants and valves are also connected directly to the distribution mains. Further, services also called service line were laid and transmit water from the distribution mains to end customers.

### 2.3.2 Reservoir and storage tanks

In the water distribution system, reservoir and storage tanks are mainly provided in order to meet the fluctuations of water demand and to stabilize pressure within the distribution system. Similarly, these components were reserve water for emergency requirements. Accordingly, the common reservoirs established in the water supply system are circular and/or rectangular type which builds either from concrete or steel materials. And, the recommended locations of such facilities are mainly in elevated area beyond the center of service area (NRC, 2006).

Reservoirs are used to model any source of water where the hydraulic grade is controlled by factors other than the water usage rate.  Lakes, groundwater wells, and clear wells at water treatment plants are often represented as reservoirs in water distribution models.

For modeling purposes, a municipal system that purchases water from a bulk water vendor may model the connection to the vendor's supply as a reservoir (most current simulation software includes this functionality).

For steady-state runs, the tank is viewed as a known hydraulic grade elevation, and the model calculates how fast water is flowing into or out of the tank given that HGL. Given the same HGL setting, the tank is hydraulically identical to a reservoir for a steady-state run.

### 2.3.3 Junction

As the term implies, one of the primary uses of a junction node is to provide a location for two or more pipes to meet. Junctions, however, do not need to be elemental intersections, as a junction node may exist at the end of a single pipe (typically referred to as a dead-end).

The other chief role of a junction node is to provide a location to withdraw water demanded from the system or inject inflows (sometimes referred to as negative demands) into the system. Junction nodes typically do not directly relate to real-world distribution components, since pipes are usually joined with fittings, and flows are extracted from the system at any number of customer connections along a pipe.

### 2.3.4 Pipes

Swamee P and Sharma A, (2007); explained that pipe conveys flow as it moves from one junction node to another in a network. In the real world, individual pipes are usually manufactured in lengths of around 18 or 20 feet (6 meters), which are then assembled in series as a pipeline. Real-world pipelines may also have various fittings, such as elbows, to handle abrupt changes in direction, or isolation valves to close off flow through a particular section of pipe. For modeling purposes, individual segments of pipe and associated fittings can all be combined into a single pipe element. A model pipe should have the same characteristics (size, material, etc.) throughout its length.

### 2.3.5 Pump Stations

As per Chambers, *et al.,* (2004); Pumps are used for convey energy to the water in order to boost water at higher elevations.

Most pumps used in the water supply systems are centrifugal in nature, and are installed to improve the water distribution, if gravity is insufficient to supply water at an adequate pressure. So that, to control the operational condition of pumps switch-board were provided in the station.

### 2.3.6 Accessory equipment

The accessory equipment in the water distribution pipelines can be classified as fittings, valves (such as; control valves, air release valves, pressure reducing valves), hydrants, drainage facility, flow meters, and etc. All these accessories has been installed at places were necessary for connecting the network, controlling and management of the system, and for maintenance purposes during failure is occur (Bhadbhade, 2009). There are many reasons and factors why a pump is not performing well in a certain situation of water distribution system.

But, as per Marta & Rudolf, (1987); the important and possible reasons to less performing of pumps were identified as below; When the pump is of poor design and quality, If it is not suitable for the given situation and does not work in its optimal range, If the pump is not being used properly and maintained regularly (cleaning, greasing, etc.), If the pump is excessively exposed to sun, rain, dust. If it is overused and was not repaired properly after a break-down and if supply of spare parts is difficult.

## 2.4 Poor infrastructures

In most of the developing countries it has been observed that pipe network is very old and which is laid many years ago. With aging problem there is considerable reduction in carrying capacity of the pipelines. Although, most of the distribution pipeline were get corroded and leakage were occur, since resulting in loss of water and pressure reduction. Hence, ‘All these materials suffer from degradation over time and result in leakage in the network. It is, therefore, Preventive maintenance of distribution system assures and providing conditions for adequate flow through the pipelines. Incidentally, this will prolong the effective life of the pipeline and restore its carrying capacity.

Some of the main functions in the management of preventive maintenance of pipelines are assessment, detection and prevention of loss of water from pipelines through leaks, maintaining the capacity of pipelines, cleaning of pipelines and relining' (Dighade, *et al*., 2014).

## 2.5 Operation and maintenance activities

'Water distribution systems are occasionally subject to emergencies or planned maintenance activities in which certain components become not workable and the system can no longer provide the minimum level of service to customers. Planned maintenance activities include supplies going off line (e.g., reservoir shutdown for inspection, cleaning, or repairs; installation of new pipe connections; pipe rehabilitation or break repairs; and transmission main valve repairs.) while, emergency situations include earthquakes, power failures, equipment failures, or transmission main failures. Therefore, all these activities can result in a reduction in system capacity and supply pressure, and changes to the flow paths of water within the distribution system' (NRC, 2006).

## 2.6 Water distribution network simulation

'The term simulation generally refers to the process of imitating the behavior of one system through the functions of another. It can be used to predict system responses to events under a wide range of conditions without disrupting the actual system.

Using simulations, problems can be anticipated in proposed or existing systems, and can be evaluated before time, money, and materials are invested in a real-world project' (Tomas, *et al*., 2003). As per Tomas, *et al*., 2003; in water distribution networks the most basic type of model simulations are either steady-state or extended-period simulation.

**Steady-state simulations:** represent a particular view of point in time and are used to determine the operating behavior of a system under static conditions. It compute the hydraulic parameters such as flows, pressures, pump operating characteristics, and others by assuming that demands and boundary conditions were not change with respect to time. In general, this type of analysis were used to determining the short-term effect of demand conditions on the system (Tomas, *et al*., 2003).

**Extended- period simulations:** are determine the dynamic behavior of a system over a period of time, and it analyze the system on assumption that the hydraulic demands and boundary conditions were change with respect to time. Hence, 'extended period analysis used to evaluate system performance over time and allows the user to model pressures and flow rates changing, tanks filling and draining, and regulating valves opening and closing throughout the system in response to varying demand conditions and automatic control strategies formulated by the modeler. Therefore, regardless of project size, model-based simulation can provide valuable information to assist an engineer in making well-informed decisions' (Tomas, *et al*., 2003, and Benyam, 2016).

## 2.7 Water GEMs: Modeling Capabilities

Model is something that represents things in the real world. 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 and WaterGEMS: *USER MANUAL* ).

WaterGEMs provides and allowing modeling practically for any distribution system aspect. Therefore, working with Water Gems used as for decision-support tool for water distribution network. The software helps to improve the knowledge of how infrastructure behaves as a system, how it reacts to operational strategies, and how it should grow as population and demands increase.

Some of the model capability of WaterGEMs are: Analyze pipe and valve criticality, pressure, flow and demands in the system and to see how behaves over time, access fire flow capacity, tank, pump and valve behavior in the system, identify leakage and water loss from the network, build and manage hydraulic models, manage energy use and prioritize pipe renewal.

### 2.7.1 Input data for representing the model

In practice, pipe networks consist not only of pipes, but composed of vary fittings, services, storage tanks and reservoirs, meters, regulating valves, pumps, and electronic and mechanical controls. For modeling purposes, these system elements were organized into the following categories (WaterGEMs: user manual):

Table 2.1: Network element and primary modeling purposes of WaterGEMs tools

| Element | Type | Primary modeling purpose | Input data |
|---|---|---|---|
| Reservoir | Node | Provides water to the system | Hydraulic grade line (water surface elevation) |
| Tank | Node | Stores excess water within the system and releases that water at times of high usage | Base Elevation, Max. Elevation, Min. Elevation, and Diameter |
| Junction | Node | Discharge the demand required or recharge the inflow water from/to the system | Elevation |
| Pipe | Link | transport water from one node to another | Elevation, Diameter, Material and Roughness coefficient |
| Pump | Node/Link | provide energy to the system and raise the water pressure to overcome elevation differences and friction losses | Elevation, Pump definition (Characteristics of max. operation and design discharge and head efficiency) |
| Valve | Node/link | Controls flow or pressure through a pipe and results in a loss of energy in the system | Elevation, Diameter, Valve type, |

(Source: Advanced water distribution modeling and management, Haestad method)

## 2.8 Methods of water distribution

### 2.8.1 Gravity Distribution

This is possible, when the source of supply water is at some elevation above the city, so that sufficient pressure can be maintained in the mains for domestic and fire services. The advantage of this method of distribution is saving power that needed for pumping.

### 2.8.2 Distribution by Pumping Without Storage

In this method of distribution, water is pumped directly into the mains with no other outlet than the water actually consumed. The pumping rate should be sufficient to satisfy the demand. This method is the least desirable way of distribution; the power failure leads to complete interruption in water supply.

An advantage of direct pumping is that a large fire service pump may be used which can run up the pressure to any desired amount permitted by the construction of mains.

### 2.8.3 Distribution by means of pumps with storage

In this method an elevated tanks or reservoirs are used to maintain the excess water pumped during periods of low consumption, and these stored quantities of water may be used during the periods of high consumption. This method allows fairly uniform rates of pumping and hence is economical

## 2.9 Water demand

The website www.waterhelp.org; defined water demand as; the indicator for measuring the level of water consumption is the amount of water consumed per capita per day (l/c/d). The consumption or use of water, also known as water demand, is the driving force behind the hydraulic dynamics occurring in water distribution systems. Anywhere that water can leave the system represents a point of consumption, including a customer's faucet, a leaky main, or an open fire hydrant. Three questions related to water consumption must be answered when building a hydraulic model: (1) how much water is being used? (2) Where are the points of consumption located? and (3) how does the usage change as a function of time? The water demand of a particular town is proportionally related with the population to be served. The design and execution of any water supply scheme requires an estimate of the total amount of water required by community.

The total amount of water demand is affected by the expected development of the city, presence of industries, quality of water and its cost, characteristics of the population and efficiency of the water work administration. Generally, in designing the water supply scheme for a town or city, it is necessary to determine the total quantity of water required for various purposes.

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 (the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes), Non domestic demand, Business or commercial water demand, Industrial water demand and Fire demand. One of the difficulties faced by the water service office is determining the accurate water demand if the town as the consumption during the past years that have been used as a base is far below the a actual demand due to shortage of water. The water demand can be categorized as follow and discussed by different authors:

### 2.9.1 Domestic water demand

Reynaud A, *et al.*, (2018); explained that water demand for actual household activity is known as domestic water demand. It includes water for drinking, cooking, bathing, washing, flushing, toilet, etc. The demand will depend on many factors, the most important of which are economic, social and climatic factors. The percentages of population with or without piped water connection are a relevant indictor to compare the coverage of water supply in urban areas.

### 2.9.2 Non-Domestic Water Demand

Non-domestic water demand (The water required for schools, hospitals, health Centre offices, government offices and services, religious institutions and other public facilities) was also determined systematically. It can be broadly classified into the following major categories: Institutional water demand, Commercial water demands and small scale industrial water demand (Naqamte Design Report, 2006).

### 2.9.3 Non-Revenue Water

Gungor-Demirci, *et al*., (218); explained that non-revenue water includes water losses in the water supply system, illegal connections overflow from reservoirs, improper metering and losses in treatment plant.

The amount is expressed as percentage of the sum of domestic, public and industrial demands covered from the water supply system. The percentage usually varies from 15 to 50 percent depending on the age of the pipes and complexity of the system.

### 2.9.4 Fire Fighting Demand

Amdework, (2012), and Rata, (2018); discussed that annual volume required for firefighting purpose is small. However, during periods of need, the demand may be exceedingly large and in many cases govern the design of distribution, storage and pumping requirements.

In this case the firefighting water requirements are considered to be met by stopping supply to consumers and directing it for this purpose. This demand is taken care of by increasing the volume of storage tanks by 10 % .Firefighting flows are usually accounted for in maximum daily flow. There are several time related demands that should be considered in the model such as seasonal demands, weekly demands, population growth and industrial demands. Seasonal Demands such as hot dry summers cause increase lawn watering.

## 2.10 Water demand factors

### 2.10.1 Average day water demand

As per Venkateswara, (2005); this demand is mainly depends on the general behavior of people, climatic conditions and character of city as industrial, commercial or residential. More water demand is on Sundays and holidays due to more comfortable bathing, washing etc as compared to other working days**.** The average daily water demand is the sum of the domestic, non-domestic and unaccounted for water which is used to estimate the maximum day & the peak hour demand. The average day demand is used in economic calculations over the projects lifetime.

$$\text{Qavg} = \text{Per capita water consumption} * \text{Total population of the town} \tag{2.1}$$

Where, Qavg = Average day demand (cfs, m3/s)

### 2.10.2 Maximum day water demand

The water consumption varies from day to day. In dry season the water demand is maximum, because the people will use more water for bathing, cooling, lawn watering and street sprinkling. The maximum day water demand is considered to meet water consumption changes with seasons and days of the week.

$$\text{Qmax} = \text{PF} * \text{Qavg} \tag{2.2}$$

Where, Qmax = Maximum day demand (cfs, m3/s)

PF = Peaking factor between maximum day and average day demand

Qavg = Average day demand (cfs, m3/s)

The ratio of the maximum daily consumption to the mean annual daily consumption is the maximum day factor. Hence, maximum day demands can be obtain by multiplying the average-day demands to the peaking factor applied to the node' (Venkateswara, 2005).

### 2.10.3 Peak Hour Water Demand

In most developing countries the maximum hour water demand is happen during morning and evening time over 24 hour, because in these time most people use water for bathing, washing and cooking purpose. The peak hour demand is the highest demand of any one hour over the maximum day. It represents the daily variations in water demand resulting from the behavioral patterns of the local population Experience clearly demonstrates that the peak hour factor is greater for a smaller population. The recommended peak hour factors in relation to population size (Venkateswara, 2005, and).

$$\mathrm{Qhour} = \mathrm{PF} * \ \mathrm{Qavg} \tag{2.3}$$

Where, Qhour = Peak hour demand (cfs, $m^3/s$)
PF = Peaking factor between maximum hour and average day demand
Qavg = Average day demand (cfs, $m^3/s$)

Table 2.2: Recommended peak hour factors

| Population Range | Peak hour factor |
|---|---|
| <20,000 | 2 |
| 20,001 to 50,000 | 1.9 |
| 50,001 to 100,000 | 1.8 |
| >100,000 | 1.6 |

(Source: Urban Water Supply Design Criteria by Ministry of Water Resources)

## 2.11 Model calibration and validation

Takahashi, *et al*., (2010); demonstrated that the calibration process of water distribution system models allows for accurate and reliable hydraulic analysis results. Thus, calibration is of utmost importance if adequate operation and maintenance model-based procedures are sought. However, in emerging economies, there is a series of factors that make it more difficult to construct accurate models, including very poor information management, unusually high leakages and the presence of a large number of illegal connections.

While some of the model variables are assumed to be known under normal circumstances, these factors make it necessary to consider them for calibration as well.

Gregory, (2002); forwarded that ‘Model calibration is the process of fine-tuning a model until it simulates field conditions for a specified time horizon to an established degree of accuracy’. Fine-tuning includes making minor. Adjustments to the input data to achieve the desired output data’. Therefore, model will not be hundred percent correct and to be calibrating it must be accurately simulate the observed data. So that, calibration is a major portion of modeling process and proper calibration were achieved through accurate field data.

### 2.11.1 Pressure calibration

James, *et al*., (1994); made a study about distribution systems. Data about pressure and flow rate were obtained by continuous monitoring of their system. Transient analysis, time lagged calculations and inverse calculations were applied as a tool for calibration and leak detection.

Pressure readings are done using pressure gauge commonly taken at pump stations, storage tanks, reservoirs, fire hydrants, home faucets, air release and other types of valves. Collecting pressures data throughout the water distribution system used to indicate the level of service. However, different factors can contribute to deviation between model simulation and actual field data. Therefore, ‘calibration can be accomplished by adjusting only internal pipe roughness values or estimates of nodal demands until an agreement between observed and computed pressures and flows is obtained. The basis for this claim is that unlike pipe lengths, diameters, and tank levels, which are directly measured, pipe roughness values and nodal demands are typically estimated, and thus have room for adjustment’ (Tomas, et al., 2003 and Benyam,2016).

## 2.12 Pump performance tests

Pump is a device that adds energy to the system in the form of increasing hydraulic grade to water. In water distribution systems, the most frequently type of pump is the centrifugal pump. There are four types of pump characteristic curves: head, brake horsepower, efficiency, and Net positive suction head (NPSH). Although modelers can usually rely on pump characteristic curves that are provided by the manufacturer, it is good practice to check these curves against pump performance data collected in the field.

‘Typically, only the head characteristic curve is needed for modeling; however, some models determine energy usage at pump stations as well as flow and head. To determine energy usage, the model must convert the water power produced by the pump into electric power used by the pump. This conversion is done using the efficiency relationships summarized below’ (Tomas, *et al.*, 2003).

$$\mathrm{eP} = (\text{ water power out})/(\text{pump power in}) \tag{2.4}$$

$$\mathrm{em} = (\text{pump power in})/(\text{ electric power in}) \tag{2.5}$$

Where, ep = pump efficiency (%)

em = motor efficiency (%)

As per Tomas, *et al*., 2003; Pump power refers to the brake horsepower on the pump shaft, or the amount of power delivered to the pump from the motor. While, water power is the amount of power delivered to the water from the pump and it computed using the following relationship:

$$\mathrm{wp} = \mathrm{cfQhp}\gamma \tag{2.6}$$

Where, WP = water power (hp, Watts)

Q = flow rate (gpm, l/s)

hP = head added at pump (ft, m)

γ = specific weight of water (lb/ft3, N/m3)

Cf = unit conversion factor (4.058 × 10-6 English, 0.001 SI)

## 2.13 Water treatment plant

As per Jefferson B., (2003); water treatment is defined as, it is any process that improves the quality of water to make it more acceptable for a specific end-use. The end use may be drinking, industrial water supply, irrigation, river flow maintenance, water recreation or many other uses, including being returned to the environment. The raw water from the surface water, lake or reservoir is drawn into the plant through intake structure to be treated. After water treatment plant, water is delivered to the distribution system to reach or satisfy the customers.

Larger water supplies serving many properties or commercial or industrial premises usually have shared upstream treatment systems similar in principle to those used at municipal water treatment works. This means that water is fully treated before being supplied to a distribution system from where it will go on to feed consumers.

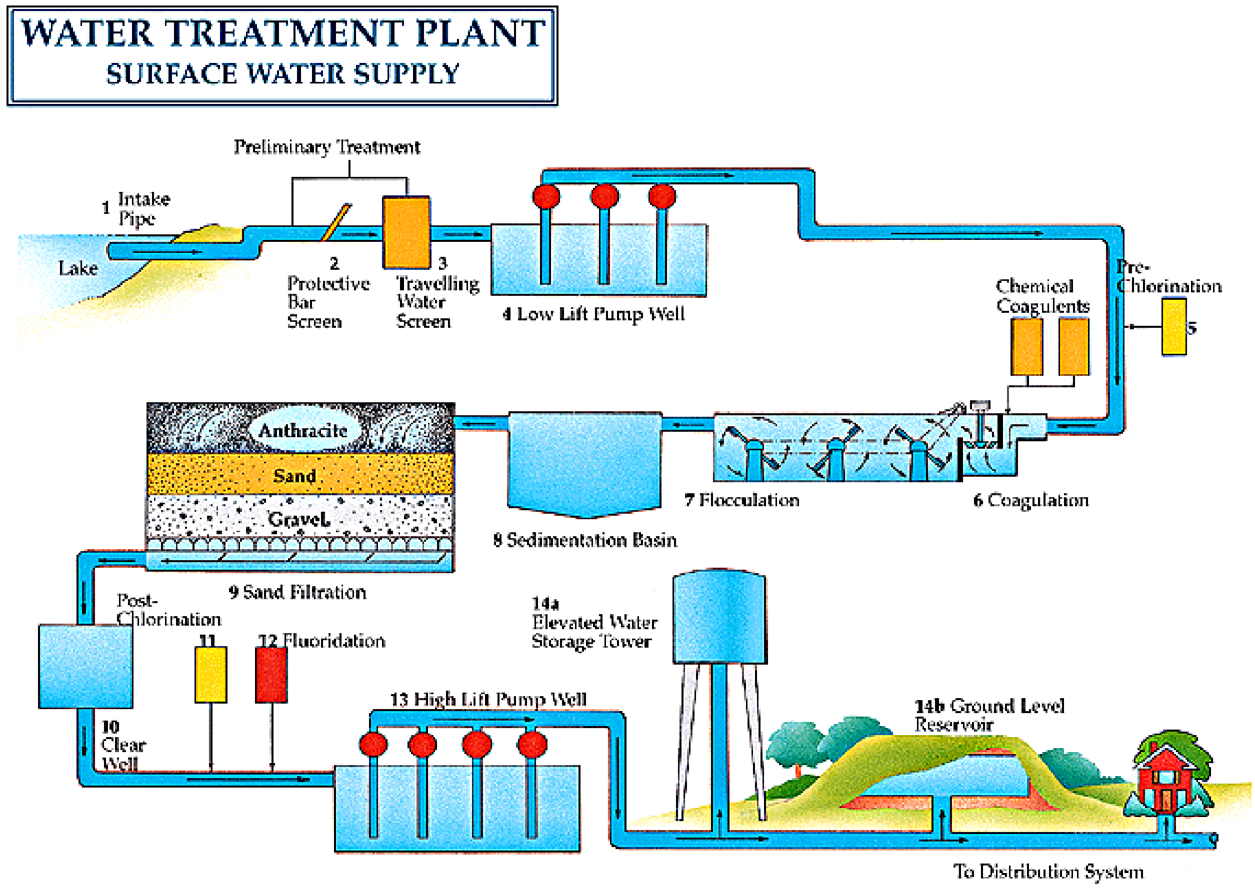


Figure 2.2: Surface water treatment flow diagram (Source: https://www.quora.com)

### 2.13.1 Conventional water treatment plant

According to Moayed H, *et al.*, (2011); surface water treatment processes are discussed as below; the major unit processes that make up the conventional water treatment plant are intake (screening), coagulation/flocculation, sedimentation, filtration, disinfection, and distribution. Once water from the source has entered to the plant as influent, water treatment processes break down into two parts, clarification and disinfection.

The first part, clarification, consists of screening, coagulation/flocculation, sedimentation, and filtration. Clarification processes go far in potable water production, but while they do remove many microorganisms from the raw water, they cannot produce water free of microbial pathogens. The second part and the final step, disinfection, destroy or inactivate disease-causing infection agents. Therefore water treatment processes are described as follow:

#### 2.13.1.1 Coagulation and flocculation

Coagulation and flocculation are used to remove color, turbidity, algae and other microorganisms from surface waters. The addition of a chemical coagulant to the water causes the formation of a precipitate, or floc, which entraps these impurities. Iron and aluminum can also be removed under suitable conditions. The most commonly used coagulants are aluminum sulphate and ferric sulphate, although other coagulants are available. The coagulant is rapidly and thoroughly dispersed on dosing by adding it at a point of high turbulence. The water is allowed to flocculate and then passes into the sedimentation tank (sometimes known as a clarifier) to allow aggregation of the floc, which settle out to form sludge. This sludge will need to be periodically removed. The advantages of coagulation are that it reduces the time required to settle out suspended solids and is very effective in removing fine particles that are otherwise very difficult to remove.

##### 2.13.1.1.1 Types of coagulant Chemicals

According to website of https://akvopedia; chemical coagulants are mentioned as follow; chemicals used in coagulation are classified as primary coagulants and coagulant aids. Primary coagulants are used to cause particles to become destabilized and begin to clump together. The purpose of coagulant aids may be to condition the water for the primary coagulant being used, to add density to slow-settling flocs or toughness so that the flocs will not break up in the following processes. Salts of Aluminum or iron are the most commonly used coagulant chemicals in water treatment because they are effective, relatively low cost, available, and easy to handle, store, and apply. Alum is the common name for Aluminum Sulphate also known as Sulphate of alumina, and is probably the most widely used coagulant in water treatment.

The classical chemical formula for Aluminum Sulphate is $Al_2(SO_4)_3.18H_2O$, but as used in water treatment it contains varying amounts of water of crystallization. It is supplied in the form of lumps with $21.H_2O$ and in granulated or kibbled form with $14.H_2O$ water of crystallization. The chemical is readily soluble but the solution is corrosive to Aluminum, steel and concrete so tanks of these materials need protective linings. The chemical is also available in liquid form. Its most effective range for coagulation is pH 5.5 - 8 and its reaction when added to water is with the natural or added alkalinity to form Aluminum hydroxide $Al_2(OH)_3$ (floc ) according to the alkalinity present.

Ferric Chloride, ($FeCl_3$) is available in liquid form, in yellow-brown lumps as crystal ferric chloride $FeCl_3.6H_2O$ or as anhydrous Ferric Chloride in green-black powder form. Its reactions in the coagulation process are similar to those of Alum, but its relative solubility and pH range differ significantly. The optimum pH range for ferric chloride is 4 to 12. Ferric chloride consumes alkalinity at a rate of about 0.75 mg/L alkalinity for every 1 mg/L of ferric chloride. Ferric chloride dosage is typically about half of the dosage required for alum. Ferric Sulphate is normally corrosive and has a low pH, although it can be supplied in solid form it is usually supplied as a solution. The strength of solution supplied is not fixed by convention as much as for the other chemicals. The purchase of Ferric Sulphate (or Ferric Chloride) is therefore often based on its iron content as Fe. Depending on solution strength this may range from about 8% up to 14%. The optimum pH range for Ferric Sulphate is similar to that of Ferric Chloride.

## 2.13.1.1.2 Evaluation of chemical coagulants

An evaluation of the chemicals used in the treatment process can identify the appropriateness of the chemicals being used. A thorough understanding of coagulation chemistry is important, and changes to coagulation chemicals should not be made without careful consideration. Essentially coagulants are evaluated to choose the best coagulant in terms of performance and cost.

There are many fundamental variables in water treatment, which will have a significant influence on the choice of type of effective coagulant chemical that could be usefully employed in a particular application. The major variables include; Changes in raw water characteristics, pH, temperature, alkalinity and turbidity.

The changes in raw water characteristics affect the type and amount of chemicals used in coagulation and, subsequently, filtration and finished water quality. Jar tests are an excellent way to determine the best type and amount of chemical (coagulant dosage) to use for varying raw water characteristics.

The coagulant dosage is dependent on the humic content of natural water and in general is proportional to the colloidal charge in the raw water. The important point about the optimum dose determination depends highly on the raw water turbidity fluctuations and on the fact that "optimum" dose does not always refer to the dose that achieves maximum turbidity removal. For example; if a 10 mg/l increment in dosage produces only a slight improvement in turbidity removal, the increased chemical costs may not warrant the higher dose. Therefore, the optimum dose is more practically thought of as the one that achieves the best turbidity removal "for the money".

In coagulation, the pH has great effect on inorganic coagulation species and the dissociation of the humic and fulvic acids. The demand for coagulant is often decreased at lower pH values, because of the increasing protonation of organics, and more positively charged coagulant species. Consequently the coagulant dosage required becomes less due the enhanced adsorption in the ideal pH. Under very low pH, precipitation may reduce, or reduce partially, following of enhanced charge neutralization and co-precipitation by adsorption.

Alkalinity is of critical importance when selecting a metal salt coagulant such as Aluminum Sulphate (Alum), or Ferric salts. All these materials need some alkalinity to drive the hydrolysis reactions that allow the coagulants to function. The precipitation of mineral turbidity by the classic coagulation and flocculation process is well defined and reasonably straight forward. Turbidity can be classified as being anionically charged particles.

### 2.13.1.1.3 Factors that affect performance of coagulation

The common design parameters that affect the efficiency of coagulation are mixing intensity and detention time.

Mixing intensity is typically quantified with a number known as the "velocity gradient" or "G value". The G value is a function of the power input into the mixing process and the volume of the reaction basin. Typical G values for coagulation mixing range from 300 to 8000 sec–1.

The time required to achieve efficient coagulation varies, depending on the coagulation mechanism involved. When charge neutralization is the mechanism involved, the detention time (T) required may be one second or less. When sweep floc or entrapment is the mechanism involved, longer detention time on the order of 1 to 30 seconds may be appropriate.

#### 2.13.1.1.4 Common problems of coagulation performance

Common problems usually occur in coagulation process are under or over-dosing, mixing of insufficient energy, fouling or clogging of injectors or diffusers and side reactions. Under or over dosing can be avoided by using the Jar Testing. Mixing of insufficient energy can cause undesirable coagulation reactions. Fouling or clogging of injectors or diffusers is usually caused either by pre-dilution of coagulant or poor mixing at the point of injection. This causes high and much localized coagulant concentrations and contributes to significant precipitation around injectors.

#### 2.13.1.1.5 Factors that affect performance of flocculators

The efficiency of the flocculation process is largely determined by the number of collisions between the minute coagulated particles per unit of time. Mixing is a key aspect of the flocculation process. Often the intensity of mixing is reduced as the water proceeds through the flocculation process to achieve optimum performance. At the beginning of the process, the mixing is fairly intense to maximize the particle contact opportunities. Mixing intensity G values in this area are typically in the range 60 to 70 sec-1. Toward the end of the flocculation process, mixing intensity is generally reduced to minimize the potential for breaking up the floc particles that have begun to form. In this portion of the process, G values are commonly in the 10 to 30 sec-1 range.

The amount of time the water spends in the flocculation process is a key performance parameter. Adequate time must be provided to allow generation of particles sufficiently large to allow their efficient removal in subsequent treatment processes.

Overall detention time (T) in the flocculation process typically ranges from 10 to 30 minutes and is generally provided in several different basins or basin segments. This allows the mixing intensity to be varied through the process. The loss of head in Alabama type of flocculator is about 0.35- 0.50 m for the entire unit.

Flocculator Inlets and Outlets are key parameters that affect the performance of flocculation. Short-circuiting occurs when water bypasses the normal flow path through the basin and reaches the outlet in less than the normal detention time. Inlet and outlet turbulence is sometimes the source of floc-destructive energy and short-circuiting in flocculation basins.

### 2.13.1.2 Sedimentation

Simple sedimentation (i.e. unassisted by coagulation) may be used to reduce turbidity and solids in suspension. Sedimentation tanks are designed to reduce the velocity of flow of water so as to permit suspended solids to settle under gravity. There are many different designs of tanks and selection is based on simple settlement tests or by experience of existing tanks treating similar waters. Without the aid of coagulation, these will only remove large or heavy particles, and due to the length of time this process will take, the system will usually require storage tanks to balance peaks and troughs in demand. The tank should be covered to prevent contamination and ingress. Sedimentation tanks require cleaning when performance deteriorates. This will not normally be more frequent than once per year.

#### 2.13.1.2.1 Factors that affect performance of sedimentation

Overflow rate, detention time, and weir loading rate are the three main parameters that affect the performance of settling basins. The efficiency of a sedimentation basin in the removal of suspended particles can be determined using, as a basis, the settling velocity of a particle that in the detention time will just traverse the full depth of the tank. Factors that influence settling velocity include the size, shape, and weight of the floe, viscosity and hence the temperature of the water, the velocity of flow, and the inlet and outlet design. Suspended solids removal and turbidity reduction rates achieved through sedimentation may range from about 50 to 90 percent, depending on the nature of the solids, the level of treatment provided, and the design of the clarifiers. Common values are in the 60 to 80 percent range.

### 2.13.1.3 Filtration

Turbidity and algae are removed from raw waters by screens, gravel filters, slow sand, rapid gravity filters or cartridge filters. The difference between slow and rapid sand filtration is not a simple matter of the speed of filtration, but in the underlying concept of the treatment process.

Slow sand filtration is essentially a biological process whereas rapid sand filtration is a physical treatment process. Many small private water supplies will rely on cartridge filters consisting of a woven or spun filter within a standard housing.

### i) Slow sand filters

Slow sand filters, sometimes proceeded by micro strainers or coarse filtration, and are used to remove turbidity, algae and microorganisms. Slow sand filtration is a simple and reliable process and is therefore often suitable for the treatment of small supplies provided that sufficient land is available.

The raw water flows downwards and turbidity and microorganisms are removed by filtration in the top few centimeters of the sand. A biological layer of sludge, known as the schmutzdecke, develops on the surface of the filter that can be effective in removing microorganisms.

### ii) Rapid gravity filters

Rapid gravity filters are most commonly used to remove floc from coagulated waters. They may also be used to remove turbidity, algae and iron and manganese from raw waters. Granular activated carbon media may be used to remove organic compounds. Rapid gravity sand filters usually consist of rectangular tanks containing silica sand and/or anthracite media (size range 0.5 to 1.0 mm) to a depth of between 0.6 and 1.0m.

The water flows downwards and solids become concentrated in the upper layers of the bed. Treated water is collected via nozzles in the floor of the filter. The accumulated solids are removed periodically by backwashing with treated water, usually preceded by scouring of the media with air.

## 2.13.1.3.1 Factors that affect performance of filtration

Improperly designed, operated, or maintained filters can contribute to poor water quality and sub-optimal performance. A host of factors may be contributing to poor performance, and systems should make a comprehensive evaluation of the filter to identify which factors are responsible, factors that affect the performance of filters are listed below.

Design of Filter Beds- Systems should verify that the filters are constructed and maintained according to design specifications. Filter Rate and Rate Control- The rate of filtration and rate control are other important aspects of filters that should be evaluated. Without proper control, surges may occur which force suspended particles through the filter media.

Filter Backwashing- Filter backwashing has been identified as a critical step in the filtration process. Many of the operating problems associated with filters may be a result of inadequate or improper backwashing. In addition to the above factors; source water quality, chemical pretreatment, filter media size/type, uniformity coefficient and surface characteristics, filter run length, filter maturation, water temperature, filter integrity and backwashing procedures also can affect performance. Ensuring that filtration processes are performing optimally helps to increase the level of protection from potential contaminants, including pathogens, in the treated water.

#### 2.13.1.4 Aeration

Air stripping is used for removal of volatile organics (e.g. solvents), carbon dioxide, disinfection by-products, some taste and odour causing compounds, and radon. It is a fairly specialist technique, and not commonly found as a treatment process on private water supplies, although aeration can sometimes be found in the oxidation stage of the treatment process for the removal of iron and manganese.

#### 2.13.1.5 Disinfection

Both surface and ground water sources typically require disinfection to eliminate or inactivate microbiological populations. The application of disinfecting agents to a potable water supply has been practiced for over a century and is recognized as one of the most successful examples of public health protection.

Historically, chlorine was the disinfectant used, but more recently other chemicals such as chlorine dioxide, chloramines, and ozone have been used to purify water.

Water treatment plants (WTPs) perform two kinds of disinfection: 1) primary disinfection, and 2) secondary disinfection. Primary disinfection achieves the desired level of microorganism kill or inactivation. Secondary disinfection maintains a disinfectant residual in the finished drinking water to prevent regrowth of microorganisms as water passes through the distribution system.

WTPs may use different chemicals for the two kinds of disinfection. Both kinds of disinfection might affect chemicals in the residuals.

**1. Primary disinfection** occurs early in the source water treatment, prior to sedimentation or filtration.

Although no residuals are generated during this treatment step, the disinfectant used (e.g., chlorine) or disinfection by-products may be present in the WTP residual waste streams (e.g., filter backwash). Chlorine, ozone with another secondary disinfectant, and UV light with another secondary disinfectant are effective primary disinfectants (National Drinking Water Clearinghouse, 1996a).

**2. Secondary disinfection** occurs at the end of source water treatment, either at the finished drinking water clear well or at various points in the distribution system. This disinfection step is used to maintain a disinfectant residual in the finished drinking water to prevent regrowth of microorganisms. The secondary disinfection process does not result in residuals generation; however, water from the clear well may be used to backwash filters. As a result, disinfectant added to the finished drinking water may become part of the filter backwash. Chlorine and chloramines are effective secondary disinfectants (National Drinking Water Clearinghouse, 1996a).

## 2.14 Methods of Disinfection

Ishaq M., *et al*., (2018), and https://www.intechopen.com; discussed that methods of disinfection as follow;

## A. Disinfection with Chlorine (Chlorination)

When chlorine is added to water, it produces nascent oxygen which kills the bacteria. The method is cheap and most reliable.

When dissolved in water, chlorine gas quickly forms hypochlorous acid (HOCl), which in turn, dissociates into hypochlorite ion (OCl-). The hypochlorous acid form of chlorine is a more effective disinfectant that the dissociated form, hypochlorite ion. Chlorine gas, however, is toxic and has a density greater than air, therefore gas leaks accumulate and present significant safety concerns.

Properly engineered gas handling systems, continuous training, or switching to a non-gaseous chlorine form like calcium hypochlorite reduce safety concerns.

The following are the types of chlorination depending up on the amount of chlorine added or the stage of treatment or the result of chlorination.

i. **Plain Chlorination: -** The plain chlorination is the process of chlorination in plain or raw water in the tanks or reservoirs. By this method bacteria is removed from water and the growth or algae is controlled. This method also helps in removing color and organic matter from water. The amount of chlorine required is 0.5 ppm.

ii. **Pre chlorination: -** when chlorine is added to raw water before any treatment i.e. before sedimentations this type of chlorination is known as pre-chlorination .The dose of chlorine applied should be such that at least 0.2 to 0.5 ppm of residual chlorine comes to the filter plant. Pre-chlorination improves coagulation reducing the amount of coagulants and reduce the lead on filters there by increasing their efficiency.

iii. **Post chlorination: -** The addition of chlorine after all the treatment being applied to water is called post chlorination. This is done before the water enters the distribution system. The amount of chlorine added should be such that residual chlorine of about 0.22pm appears in water after a contact period of 20minutes.

iv. **Double chlorination**:- If chlorine is added to water at more than one point the process is called double chlorination Both pre-chlorination and post chlorination are done when the water contains large number of bacteria's.

v. **Supper Chlorination:-**The amount of chlorine in excess of that necessary for adequate bacterial purification of water. This is done under certain circumstances such as epidemics of water borne diseases. High dose of chlorine is added to water i.e. 2-3 ppm beyond break-point for safety of public. It gives a strong odor and taste or chlorine in the treated water which is later can be removed by dechlorination.

vi. **Break-point chlorination:-**The chlorine when added in water removes the bacteria (disinfection) and oxidizes the organic matter .During disinfection the amount of residual chlorine will be less in beginning but will increase gradually as the demand for disinfection is satisfied. After this the oxidation of organic matter starts and chlorine again used and water contain less and less amount of residual chlorine as the process is continued. When this demand of chlorine is satisfied the amount of residual chlorine again increases.

The stage at which both these demands are satisfied and residual chlorine tends to increase is known as break-point. Any further dose of chlorine applied will reappear as free chlorine. Application of chlorine up to the break-point is known as break-point chlorination.

vii. **Dechlorination:-**The process of partial or complete reduction of residual chlorine in water by chemical or physical treatment of residual is known as dechlorination. In this method some chemicals are added for the purpose of reducing the chlorine residual to a desired value in water.

viii. **Chlorine demand: -** chlorine demand is defined as the difference between the amount of chlorine added to water and the amount of chlorine (free available, and combined available) remaining at the end of a specified contact period.

The chlorine demand for a sample of water depends on: Nature and concentration of chlorine consuming substances present in water, Time of contact, PH value of water, Temperature of water, Variable conditions in process of chlorination.

**B. Disinfection with water: -** The water can be disinfected by boiling for 15 to 20 minutes. All the pathogenic bacteria's can be killed by this method. This is very costly method and cannot be used for water works, but it can be used in emergency by individuals during the break up of epidemics in the locality.

**C. Disinfection with ozone: -** Ozone is very efficient disinfectant. It is used in gaseous form. This method can be used only if electricity is easily and cheaply available at water works.

**D. Disinfection with excess lime: -** Lime is usually used for reducing hardness of water. It has been noted practically that if some additional quantity of lime is added than what it actually requires for removal of hardness, it will also disinfect the water while removing the hardness. The addition of excess lime increases the PH value of the water which may be harmful to human health.

**E. Disinfection with ultra-violet rays: -** Ultra-violet rays are invisible light rays having wave lengths 1000 to 4000 mμ.

These rays are very effective disinfectant and kill all the disease producing. But this Process is costly and requires technical skill and costly equipment. This method is mainly used for disinfection of water in swimming Pool.

**F. Disinfection with potassium Permanganate:** - Potassium permanganate (KMnO4) is the most common disinfectant and used in the villages for disinfection of dug-well water, pond water or private source of water. In addition to the killing of bacterial, it also reduces the organic matters by oxidizing them. Since the efficiency of killing bacterial is 98% and not 100% and the colour of the water becomes light pink, it is not being used.

**G. Disinfection with iodine & Bromine:** - All the pathogenic bacteria can be killed within 5 minutes contact period by adding Iodine and Bromine in water but their quantity should not exceed 8ppm. These disinfectants are easily available in the form of pills and also handy. Due to the high cost, they are not used in water works of public water supplies but they are used in individual dwellings.

## 2.15 Water loss and leakage

According to website of https://iwa-network.org; water loss is defined as that water which having been obtained from a source and put into a supply and distribution system is lost via leaks or is allowed to escape or is taken for unauthorized purposes. 'Water loss' is usually considered as leakage, and 'water loss reduction' is usually referred to as 'leakage control.'

According to Dighade, *et al.*, (2014); water losses occur in all water distribution networks, even new one and it is only the volume that varies. Thereby, the volume of these losses reflects the capacity of water authorities to manage their distribution networks. In general, water losses consist of real and apparent losses. Leakage is the major source of water loss or form of water loss.

Water loss is usually quantified on the following basis:

$$\begin{aligned}&\text{Water Loss}\\&= (\text{Quantity of water put into supply}) - (\text{Non} - \text{domestic use}\\&+ \text{Domestic consumption})\end{aligned} \tag{2.7}$$

Not only this but also water loss can be expressed in terms of Unaccounted For-Water (UFW) or Non-Revenue Water (NRW). Thus, these two terms of water loss are determined as follow: Unaccounted-for water (UFW) represents the difference between "net production" (the volume of water delivered into a network) and "consumption" (the volume of water that can be accounted for by legitimate consumption, whether metered or not) (Sharma, 2008).

$$\text{UFW} = \text{“net production} - \text{consumption}$$
$$- \text{losses”} \tag{2.8}$$

Or

$$\text{Unaccounted for water} = \frac{(\text{water produced} - \text{metered water used})}{\text{water produced}} * 100 \tag{2.9}$$

Non-revenue water (NRW) represents the difference between the volumes of water delivered into a network and billed authorized consumption (Sharma, 2008).

$$\text{NR}$$
$$= \text{“Net production” – “Revenue water”(Billed Authorised Consumptio} \tag{2.10}$$

= UFW + water which is accounted for, but no revenue is collected (unbilled authorized

Consumption).

According to Welday, (2005); quantifying and characterizing water loss and leakage in a city water supply is by its nature a complex task. Beside this Leakage identification needs detailed field investigation sometimes using sophisticated equipment. Leakage is often a large source of UFW and is a Result of either lack of maintenance or failure to renewing system and also May caused for poor management of pressure zone, which result in pipe and pipe join failure.

Table 2.3: International water association (IWA): Components of water losses

<table>
<tr><td rowspan="9">System input volume</td><td rowspan="4">Authorized consumption</td><td rowspan="2">Billed authorized consumption</td><td>Billed metered consumption (including meter exported)</td><td rowspan="2">Revenue water</td></tr>
<tr><td>Billed un-metered consumption</td></tr>
<tr><td rowspan="2">Unbilled authorized consumption</td><td>Unbilled metered consumption</td><td rowspan="7">Non-Revenue Water ( NRW)</td></tr>
<tr><td>Unbilled un-metered consumption</td></tr>
<tr><td rowspan="5">Water loss</td><td rowspan="2">Apparent losses</td><td>Unauthorized consumption</td></tr>
<tr><td>Metering inaccuracies</td></tr>
<tr><td rowspan="3">Real losses</td><td>Leakage on transmission and/or distribution mains</td></tr>
<tr><td>Leakage and overflows at utility storage tanks</td></tr>
<tr><td>Leakage on service connections up to point of customer metering</td></tr>
</table>

(Source: Farley and Stuart, 2008)

According to IWA the above terminologies are defined below: System input volume is the annual volume input to that part of the water supply system. The authorized consumption is the annual volume of metered and/or non-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorized to do so. It includes water exported and overflows and leaks after the point of customer metering. Non-Revenue Water (NRW) is the difference between system input volumes and billed authorized consumption.

Water losses are the difference between system input volumes and billed authorized consumption, and consists of apparent losses and real losses.

Apparent losses consists of unauthorized consumption and all types of metering inaccuracies. Real losses are the annual volumes lost through all types of leaks, burst and overflows on mains, service reservoir and service connections up to the point of customer metering.

### 2.15.1 Water loss in distribution network

As per Dighade, *et al*., (2014); water losses occur in all water distribution networks, even new one and it is only the volume that varies. Thereby, the volume of these losses reflects the capacity of water authorities to manage their distribution networks. In general, 'water losses consist of real and apparent losses. And to most water utilities, the level of Non-Revenue Water (NRW) is a key performance indicator of efficiency.

Utility managers should use the water balance to calculate each component and determine where water losses are occurring. By quantifying NRW from the water balance concept, volumes of lost water into system can be calculate and they will then prioritize and implement the required policy changes and operational practices which lead to the proper understood and take the required actions' (Farley, *et al*., 2008).

As per Sharma, 2008; for Understanding and Managing Losses in Water Distribution Networks the general steps to be followed are: Analysis of network characteristics and operating practices, Quantification water losses and Use of appropriate tools and mechanisms to suggest appropriate solutions. Water loss levels (UFW or NRW) vary widely per country and within one country per city UFW values ranging from 6% to 63% have been reported Water and Wastewater Utility Data.

#### 2.15.1.1 Pressure and leakage

As per Welday, (2005); in many water network systems, even though the total demand and the total loss of water can be known rather easily, information about the possible influence of local pressure upon demand is sadly lacking that as a result creates the difficulty to assess and compare the demand and loss of water in its spatial distribution.

Pressure distribution system on the one hand contributes to the increase of leakage, when it is more, on the other hand when it is low contributes to the shortage of water that as the result causes for unequal distribution of water among the residents. To alleviate such problems, some water authorities develop a zoning scheme whereby the complete water distribution is broken down into manageable segments that can be easily metered and monitored and analyzed.

Wallingford HR., (2003); showed that the leakage from distribution network has been shown to be directly proportional to the square root of the distribution system pressure as indicated by the relationship below.

$$\text{Leakage} \propto \sqrt{\text{distribution system pressure}} \tag{2.11}$$

Burst rates are also a function of pressure. The strength of the relationship and the quantification of it, is not as well understood as the relationship between flow rate and pressure. However, there is still considerable evidence to show that burst frequency is very proportional to pressure. Indeed it has even been suggested that there could be a cubic relationship i.e. burst frequency proportional to pressure cubed (Farley and Trow, 2003).

Pressure variation in distribution network is caused, among others, by changes of demand of users. The demand usually reaches a peak in the morning when the people are at home and preparing their meal and its second peak in the evening.

Obradovie, (2000); studied that if one compares daily diagram for total demand of the whole system with corresponding data captured at the level of ( relatively small) demand management areas one will discovers that the first has much smaller amplitude in comparison in the later. The minimum night flow (MNF) is relatively higher and the morning/evening peaks are less prominent.

Pressure control valves are sometimes in outlet mains from service reservoirs in order to reduce the pressure to low lying zones, or to limit increases of pressure at night to reduce leakage. Pressure reducing valves (PRV) throttle automatically to prevent the downstream hydraulic grade from exceeding a set value, and are used in situations where high downstream pressure could cause damage (Walski, *et al*., 2003).

Figure 2.3; below illustrates that a connection between pressure zones without PRV, the hydraulic grade in the upper zone could cause pressure in the lower zone to be high enough to burst pipes or cause relief valves to open.

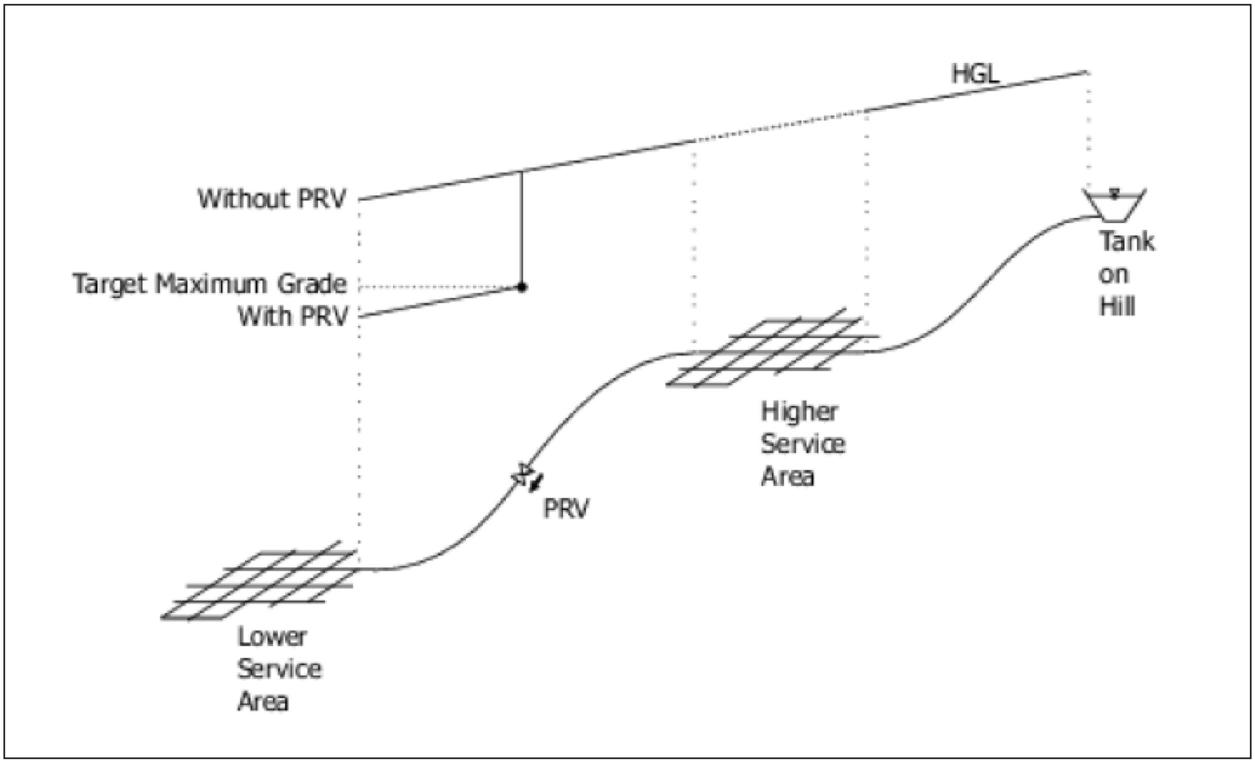


Figure 2.3: Schematic network illustrating the use of a PRV (Source: Walski, *et al*., 2003)

Farley and Trow, (2003); suggested that reducing pressure on the other hand may make existing leaks more difficult to find, because they make less noise, or do not come up to the surface. Therefore, pressure reducing should coordinated with leakage detection and repair operations.

#### 2.15.1.2 Age of pipes and leakage

As per Twort A.C, *et al*., (1994); Pipe age and material are important factors contributing to the burst of pipes that as a result cause a lots of water loss. However, as this information is mostly not available especially for aged pipes, it is usually estimated using the history of urban development.

Reports from undertakings collected by the WRC, and evidences from elsewhere suggest that leakage rates from mains are of the order of 100 to 200 l/hr per km for newer mains and 150 to 300 l/hr per km for older mains. Assuming an average of 100 connections per km these figures would represent 1.0 to 3.0 l/hr per connections.

Leakage is frequently the largest component of UFW and includes distribution losses from supply pipes, distribution and trunk mains, services up to the meter, and tank.

The amount of leakage varies from system to system, but there is a general correlation between the age of a system and the amount of UFW.

Newer systems may have as little as 5 percent leakage, while older systems have 40 percent leakage or higher (Walski, *et al.*, 2003). Although pipe age is considered as an indicator for predicting the break rate of mains, it is not the major determinant factor for main water break rate. Hence, poor design, deterioration of pipe material, unanticipated load condition will also result in pipe breakage.

### 2.15.2 Physical / Real Loss

Rios J, *et al*., (2014); discussed that 'Physical losses, sometimes called 'real losses', are the annual volumes lost through all types of leaks, bursts, and overflows on mains, service reservoirs and service connections up to the point of customer metering. So, utility managers must be verify the physical loss assessment of town's water distribution system'.

#### 2.15.2.1 Leakages from reservoirs and storage tanks

According to Farley, *et al*., (2008); Leakage and overflows from reservoirs and storage tanks are easily quantified. By observing overflows, utility experts can estimate the duration and flow rate of the events. While, most overflows occur at night when demands are low, therefore it is essential to undertake regularly night observations. 'Observations can be undertaken either physically or by installing a data logger which record reservoir levels automatically at preset intervals. Also, leakage from tanks is calculated using a drop test were the utility closes all inflow and outflow valves, measures the rate of water level drop, and then calculates the volume of water lost'.

#### 2.15.2.2 Leakage from transmission and distribution mains

As per Dighade, *et al*., (2014); Leakages occurring from transmission and distribution mains are usually large in volume. Thus, considerable volume of water is lost through bursts, leaking pipes, joints, valves and fittings of distribution system components.

These causes are usually as result of age of the installations, bad quality of materials used, and poor workmanship. Although this factors were lead to reduction of pressure in the distribution network and intermittent in water supply.

### 2.15.3 Commercial/ Apparent Loss

According to Farley, *et al.*, (2008); Commercial loss is also refer to as apparent losses, and it consist of unauthorized consumption, all types of metering inaccuracies and data handling errors. It also include water that is consumed but not paid by the users. In the developing countries, metering inaccuracies (mainly under recorded problem) and illegal users of water within the distribution system is the common problem of water losses.

Whereby, they contribute large coverage to apparent losses, so the level of these losses were one of the significant concern in developing country water distribution systems (Dighade, *et al.,* 2014).

## 2.16 Consequences of water loss and leakage

Perdikou S, *et al.*, (2014); studied that financial crisis is the prime consequences of leaks in distribution system. Reduction in water loss enables water utility to use existing facilities efficiently, alleviate shortage of water supply, improving the supply capacity to customers and the reduction of operational expenditures that are related to power and chemical costs. Reduction of water loss the service life of existing water supply components that as a result to meet the present as well as the future needs of the residents without construction of many new water facilities. The operational and maintenance costs including price of energy, chemical and other items that are constantly rising will also be aggravated by the increase of water loss due leakage.

Thus, leakage greatly contributes to loss of revenue due to illegal connection and unregistered consumption. Beside direct effect on operation and management costs, leaks have great consequence on the quality of services. The water that escapes through leakage causes a damage of structure such as road destruction, floods that affect especially the product of agriculture and changes the landscape and the like.

## 2.17 Causes of water loss

According to Beckwith H, (2014); Leakage is usually the major source of water loss in developing countries, but this is not always the case in developing or most of developed countries, where illegal connections, customer meter reading inaccuracy, unauthorized consumption and, data handling and accounting errors are often more significant.

The other components of total water loss are non-physical losses, e.g. meter under registration, illegal connections and illegal and unknown use (WHO, 2001).

## 2.18 Controlling and monitoring water loss and leakage

Aburawe S, and Mahmud A, (2011); forwarded that in order to control water loss methods like leak detection in the field and repair, rehabilitation and replacement program, corrosion control, pressure reduction and public education program Legal provisions such as, water pricing policies encouraging conservation, human resources development and information system development also need to be employed.

The losses and leakage of water are inevitable in the process of water distribution network as well as starting from the reservoirs at the treatment plant, through a complex network to the individual customers.

Mulwafu W. *et al*., (2003); suggested that leakage monitoring and control in pipe reticulation systems is critical in ensuring the efficiency performance of the system. Pipe systems are commonly used for distributing water to areas of consumption. If pipes are worn-out, large volumes of treated water may be lost through leakage as a result of high pressure of flow. Leakage control is possibly one of the most difficult tasks for water engineers. Even in developed countries, about 15-20% of the distributed water is lost through pipe leakage. It is therefore important to ensure that leakage monitoring and control given the attention it deserves by all water supply authorities and consumers.

## 2.19 Leakage assessment methods

As per Hunaidi, *et al.*, (2004); quantification of the total amount of water lost is achieved by conducting a system-wide water audit, which is known internationally as a water balance.

Audits provide a valuable overall picture of the various components of consumption and loss, which is necessary for assessing a utility's efficiency regarding water delivery, finances, and maintenance operations. Additionally, water audits are necessary for planning other leakage management practices. There are different solutions for leakage reduction in water distribution networks. Some of them are structural solutions such as using pressure reducing valves or pump stations in appropriate locations.

# CHAPTER THREE

# METHODOLOGY

## 3.1 Description of the study area

Naqamte town is the capital of East Wollega Zone of Oromia, located at the distance of 330 km west of Finfinne/Addis Ababa, centered at between 9°5'N and 36°33'E. Based on the 1:50,000 scale topographic map of the Ethiopian mapping authorities, the elevation of the town varies between 2060 and 2180 masl and with a total area of 3580 ha.

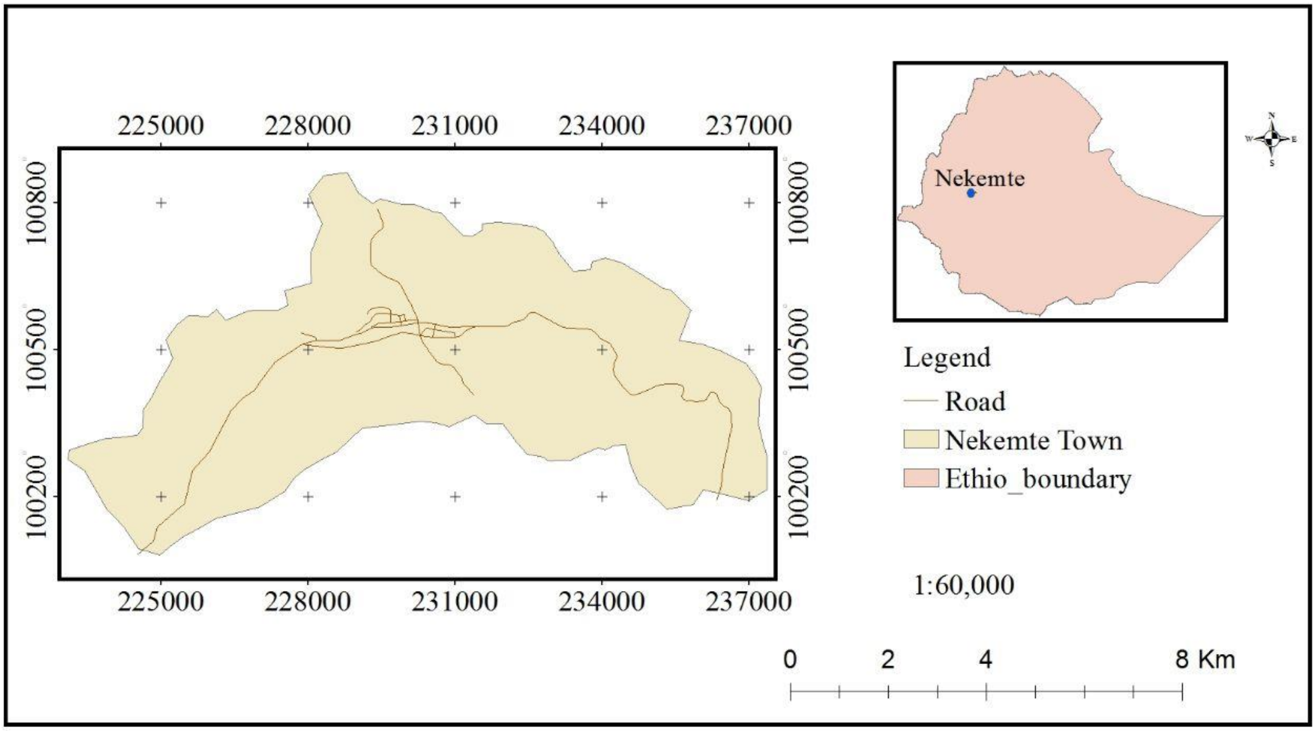


Figure 3.1: Location map of the study area

## 3.2 Population

According to the Ethiopian Central Statistical Agency (CSA), the last census population data of Naqamte town was 75,834 of whom 38,385 were men and 36,834 were women for the year 2007. According to the administration office of the town, now a days the number of the population is around 137,171 (2019 G.C) of whom 67,585 and 69,586 are male and female respectively.

## 3.3 Climate

Naqamte has a meteorological station since 1971. It is characterized by mild and moderate climate condition and lies in the middle agro-ecological (Badda-dare) zone. According to records at Naqamte town the mean annual rainfall is about 2000 mm. The main rainy season accounting for 80% is from May to September. There are small rains in March and April. The mean monthly temperature is 18$^{o}$C and mean maximum temperature is 27 $^{o}$C while the mean monthly minimum temperature is 11 $^{o}$C.

## 3.4 Existing Water Supply System of the town

The existing water supply of Naqamte town is from a small dam constructed on the Adiya River and with a treatment plant and distribution network constructed some 34 years back for a population projected for 10 years. It was designed to supply the targeted population of 31,000 by year 1985 E.C. The capacity of this dam has been recorded to be insufficient to store water required and compensate low or no flow of the river in the beginning of the months of June. Further, irrigation activities upstream, aggravates the problem resulting in complete drying out of the river and interruption of water supply production. In addition this small dam is getting silted up so that it’s almost out of services. Hence, in order to solve the water supply of the town another existing water supply system is from a Maka dam constructed on Maqa stream and on which this study focused and described as follow;

According to the evidences obtained from Naqamte town water service office, the existing water supply system work is done under the consultancy service of DH Consult wherein Ethiopian Waterworks Construction Enterprise (EWWCE) has performed civil engineering works such as construction of treatment plant, reservoirs, pipe laying, including transmission main, gravity main, and distribution mains. Oromia Waterworks Construction Enterprise (OWWCE) has also the responsibility of constructing surface reservoir and has also given the responsibility of electromechanical supplies. The construction work of the scheme was constructed about 13 years ago in 2006 G.C for targeted population of 80,640 and for a design period 10 years. The system was designed to process and distribute drinking water to the residents of Naqamte Town at the rate of 98.5 l/s. Although this is not enough to serve the current largely growing population of the town.

Detail information were gathered for clear understanding of the existing water supply demand, coverage, service level, operation, and maintenance of the scheme from Water Supply and Sewerage Authority Office.

The existing water supply is not sufficient for various purposes in the town due to huge population of the town needs additional protected water supply sources in the views of beneficiaries both from the commercial, public, investments, industrial, manufacturing and domestic consumption due the scarcity of potable water of the existing scheme. This is because of the increased day to day life of the community (living standards).

The existing water distribution system of the town composed of different units: pipes, valves, tanks, intake weir, raw water pumping station, slow sand filtration, chlorination system, 2000$m^3$ reinforce concrete service reservoir( lower zone), 500$m^3$ (upper zone) reinforced concrete service reservoir, customers service connection and transmission and distribution pipe system. Most of these components encountered with a lot of problems like pipe bursting, corrosion, disjoint of elbows, disruption by animal or humans, carelessness of regular supervision, lack of skill workmanship and etc. Hence, such problem causes water loss, leakage, contaminated water, shortage of potable water, exposes life of the residents to danger and etc.

### 3.4.1 Potential source of water

Naqamte experiences a mean annual rainfall of about 2070 mm. Over 80 percent of rainfall occurs during May to September. A relatively cheaper water source in the vicinity of Naqamte Town is the Maqa stream. The catchment is located southwest of Naqamte town. The stream flows in a westerly direction towards Kolobo village. The catchment is bounded in the north by the Naqamte-Gimbi road and in the east by the Naqamte-Arjo road. Other streams are either too small to be considered as adequate water supply source for the town or require high pumping and long conveyance facilities. Maqa stream situated at a location of $9^0$ 0.1' North and $36^0$ 28.2' East at about 14 km far from the town center. It has a catchment of 15.2$km^2$. The Maqa catchment lies between 22180 and 2260 m a.s.l.

### 3.4.2 Level of water supply consumptions

#### 3.4.2.1 Mode of water distribution

As per Naqamte town water service office, there are four major modes of services for domestic water consumers of Naqamte town. These are; public fountains, house connections, commercial connections, and government connections. But, those populations not served from any of these modes of services are categorized as traditional source users (TSU). According to Naqamte Town Water Service Office there is no TSU in the town. But despite their idea, well users are inevitable privately.

#### 3.4.2.2 Existing tariff structure

The tariff structure for consumption is mixed system (flat and graded). Public fountains are charge flat rate that is the same rate for all consumptions. Private, commercial, and government connections are charged progressive rate, i.e. a tariff rate that increases with the level of consumption. There are four level of consumption. The blocks and the rates that have been revised by the board of the water enterprise and operational since 2005.

Table 3.1: Existing water charge

| Block number | Range ($m^3$) | Charge (birr/$m^3$) |
|---|---|---|
| Public fountains | All consumers | 2.8 |
| 1 | 0-3 | 2.8 |
| 2 | 4-7 | 3.75 |
| 3 | 8-11 | 4.00 |
| 4 | >11 | 5.00 |

(Source: NWSS design report, 2006)

Table 3.2: Growth rate for different mode of consumers

| Distribution category | Percent consumed in volume | Growth rate |
|---|---|---|
| Private connection | 47% | 14% |
| Commercial connection | 16.5% | 10% |
| Government connection | 33.8% | 2% |
| Public fountains | 2.7% | fluctuates |

(Source: NWSS design report, 2006)

### 3.4.3 Raw water pump station

In the raw water pumping station there were three surface horizontal centrifugal types of pumps (Two operational and the other standby) with a design flow of 33l/s per pump. These pumps were sucked water from the water source to transmission line and treatment plant at the same time. As per Naqamte town water service office, the pumps currently operating in the system were installed before 13 years ago and performed without replacing by the new one.

### 3.4.4 Clear water collecting tank

Filtered water is collected in this unit and disinfected by hypochlorite solution. The clear disinfected water is then conveyed to both upper zone and lower zone reservoirs from this tank. Adjacent to this tank a pump station room is provided from where small pumps lift clear water from the tank to the backwash tank. The clear water tank capacity is determined taking 30 minutes detention time and is found to be $177m^3$ in volume. Two hypochlorite solution preparation and feeding tanks, each with $2.5m^3$ is provided in the operation building at an elevation that an enables gravity flow with sufficient velocity in chemical feeding pipe. This clear water collection tank also supplies water to the elevated backwash tank of 165 $m^3$, located about 8 m above ground level by pumping mechanism.

### 3.4.5 Rising main and distribution pipeline network

The transmission and distribution main line consists of branching system with a total sum length of 52,100 m, and supplying water through public fountain and yard connections by gravity means. The rising main transmit clear water simultaneously into the distribution network and service reservoir. As observed from the drawn distribution layout; there was one flushing device (wash out valve), one air release, and one pressure reducing device was installed in transmission line at to connect a low pressure area of the town. Currently, the PRV was damaged. Due to this pipe burst is occur frequently which is one of the cause of water loss. The treated water is also further connected by distribution main line which serves the population by gravity means. The water transmission main from intake to the water treatment plant is with the diameter of 400 mm and total length of 4984 m with a material of k9, DCI.

As per the document of DH consultant the distribution network was constructed by PVC pipes of diameters ranging from 80mm to 350mm with a total length of 26,550m for lower zone and 16,450m for upper zone reservoirs and DCI pipes of diameter 400mm and 500mm with a total length of 9,100m for lower zone and no DCI pipe was needed for upper zone of reservoirs.

Table 3.3: Distribution network pipe size and length

| Types of pipe | Diameter (mm) | Length (m) |
|---|---|---|
| PVC and HDPE | 80-350 | 43000 |
| DCI | 400-500 | 9100 |
| Total | | 52100 |

(Source: DH Consultant, 2006)

### 3.4.6 Service reservoirs

There are two reservoirs (circular type) serving the upper and lower zones of the town. The upper zone is with the capacity of 500 $m^3$ and internal diameter of 12.65 m and clear height of 4.75 m and the lower zone is with the capacity of 2000 $m^3$ and internal diameter of 22.5 m and clear height of 5.6 m. As per the document of DH Consultant, these two reservoirs are used to balance the hourly water demand variation of the maximum day demand. Generally, during night time they store water and in the day time they supply and deplete to replenish again when the demand of the town starts declining.

Table 3.4: Hourly demand variation coefficient

| Hour of the day | Variation coeff. |
|---|---|
| 0.00 | 0.3 |
| 1.00 | 0.3 |
| 2.00 | 0.3 |
| 3.00 | 0.3 |
| 4.00 | 0.3 |
| 5.00 | 0.3 |
| 6.00 | 1.10 |
| 7.00 | 1.80 |
| 8.00 | 1.90 |

| | |
|---|---|
| 12.00 | 1.40 |
| 13.00 | 1.30 |
| 14.00 | 1.20 |
| 15.00 | 1.40 |
| 16.00 | 1.50 |
| 17.00 | 1.50 |
| 18.00 | 1.30 |
| 19.00 | 1.00 |
| 20.00 | 0.70 |
| 21.00 | 0.50 |

| | | | | |
|---|---|---|---|---|
| 9.00 | 1.80 | | 22.00 | 0.40 |
| 10.00 | 1.60 | | 23.00 | 0.30 |

(Source: NWSS design report, 2006)

### 3.4.7 Power supply units

The power supply was from EEPCO with 15kv high voltage overhead line. Pole mounted step down transformer of 100 KVA was installed at the treatment plant compound. The water distribution system was operated for 24 hours of its design period. There is standby diesel generating set covering 100% of the total load i.e. 105 KVA was also installed at the treatment plant compound. Hence, the scheme provides good flexibility during power failure.

### 3.4.8 Hazen-Williams roughness coefficients (C-values)

The Hazen-Williams equation was developed for the action of friction at the pipe wall, because its formula uses a pipe carrying capacity factor.

Higher C-factors represent smoother pipes (with higher carrying capacities) and lower C-factors describe rougher pipes (Tomas, *et al.*, 2003 and Benyam, 2016). The value of roughness coefficient, C-factor is depending on pipe materials and its age; this effect can be shown in Table 3.6 and 3.7 below (Tomas, *et al*., 2003 and Benyam, 2016).

$$h_L = \frac{C_f Q^{1.852}}{C^{1.852} D^{4.87}} \qquad (3.1)$$

Where: hL = head loss due to friction (ft, m)
L = distance between sections 1 and 2 (ft, m)
C = Hazen-Williams C-factor
D = diameter (ft, m)
Q = pipeline flow rate (cfs, m3/s)
Cf = unit conversion factor (4.73 English, 10.7 SI)

As per Naqamte town water service office, DCI, HDPE and PVC pipe laid in the water distribution network was served without replacement work for the last 34 years. Hence, this pipe age is the main factor for water loss in the water distribution system.

Table 3.5: Roughness coefficient, C-factors for various pipes material

| Type of Pipe | C-factor Values for Discrete Pipe Diameters<br>1.0 in. (2.5 cm) | 3.0 in. (7.6 cm) | 6.0 in. (15.2 cm) | 12 in. (30 cm) | 24 in. (61 cm) | 48 in. (122 cm) |
|---|---|---|---|---|---|---|
| Uncoated cast iron - smooth and new | | 121 | 125 | 130 | 132 | 134 |
| Coated cast iron - smooth and new | | 129 | 133 | 138 | 140 | 141 |
| 30 years old | | | | | | |
| Trend 1 - slight attack | | 100 | 106 | 112 | 117 | 120 |
| Trend 2 - moderate attack | | 83 | 90 | 97 | 102 | 107 |
| Trend 3 - appreciable attack | | 59 | 70 | 78 | 83 | 89 |
| Trend 4 - severe attack | | 41 | 50 | 58 | 66 | 73 |
| 60 years old | | | | | | |
| Trend 1 - slight attack | | 90 | 97 | 102 | 107 | 112 |
| Trend 2 - moderate attack | | 69 | 79 | 85 | 92 | 96 |
| Trend 3 - appreciable attack | | 49 | 58 | 66 | 72 | 78 |
| Trend 4 - severe attack | | 30 | 39 | 48 | 56 | 62 |
| 100 years old | | | | | | |
| Trend 1 - slight attack | | 81 | 89 | 95 | 100 | 104 |
| Trend 2 - moderate attack | | 61 | 70 | 78 | 83 | 89 |
| Trend 3 - appreciable attack | | 40 | 49 | 57 | 64 | 71 |
| Trend 4 - severe attack | | 21 | 30 | 39 | 46 | 54 |
| Miscellaneous | | | | | | |
| Newly scraped mains | | 109 | 116 | 121 | 125 | 127 |
| Newly brushed mains | | 97 | 104 | 108 | 112 | 115 |
| Coated spun iron - smooth and new | | 137 | 142 | 145 | 148 | 148 |
| Old - take as coated cast iron of same age | | | | | | |
| Galvanized iron - smooth and new | 120 | 129 | 133 | | | |
| Wrought iron - smooth and new | 129 | 137 | 142 | | | |
| Coated steel - smooth and new | 129 | 137 | 142 | 145 | 148 | 148 |
| Uncoated steel - smooth and new | 134 | 142 | 145 | 147 | 150 | 150 |

Table 3.6: Roughness coefficient, C-factors for various pipe material (Cont...)

| Type of Pipe | C-factor Values for Discrete Pipe Diameters 1.0 in. (2.5 cm) | 3.0 in. (7.6 cm) | 6.0 in. (15.2 cm) | 12 in. (30 cm) | 24 in. (61 cm) | 48 in. (122 cm) |
|---|---|---|---|---|---|---|
| Coated asbestos cement - clean | | 147 | 149 | 150 | 152 | |
| Uncoated asbestos cement - clean | | 142 | 145 | 147 | 150 | |
| Spun cement-lined and spun bitumen- lined - clean | | 147 | 149 | 150 | 152 | 153 |
| Smooth pipe (including lead, brass, copper, polyethylene, and PVC) - clean | 140 | 147 | 149 | 150 | 152 | 153 |
| PVC wavy - clean | 134 | 142 | 145 | 147 | 150 | 150 |
| Concrete - Scobey | | | | | | |
| Class 1 - Cs = 0.27; clean | | 69 | 79 | 84 | 90 | 95 |
| Class 2 - Cs = 0.31; clean | | 95 | 102 | 106 | 110 | 113 |
| Class 3 - Cs = 0.345; clean | | 109 | 116 | 121 | 125 | 127 |
| Class 4 - Cs = 0.37; clean | | 121 | 125 | 130 | 132 | 134 |
| Best - Cs = 0.40; clean | | 129 | 133 | 138 | 140 | 141 |
| Tate relined pipes - clean | | 109 | 116 | 121 | 125 | 127 |
| Prestressed concrete pipes - clean | | | | 147 | 150 | 150 |

(Source: AWDM, Tomas, *et al*., 2003)

## 3.5 Existing water treatment plant of the town

As per information obtained from Naqamte town water service office, the existing Naqamte town water treatment plant electro mechanical work was constructed by Yadot Engineering Private Limited Company (PLC) in 2008 G.C. Water treatment plant is the structure at which drinking water is treated and then by the aid of water distribution networks it is conveyed to the consumers' end point. The design of the treatment plant was having pre-treatment unit of horizontal roughing filtration unit and rapid sand filtration unit. The chemicals like alum, lime and chlorine are added to the water following its sequences. Like that of others water treatment process is held for the town's water supply i.e. coagulation, flocculation, sedimentation, filtration, and etc.

One of the popular methods of disinfection used for the town water treatment is disinfection by chlorine which has a great power of killing the diseases causing organisms (pathogens). Here, this chlorination has its own side effect by emerging disinfection by-product. Thus, instead of chlorine if chlorine dioxide is used the amount of disinfection by- product is hugely reduced.

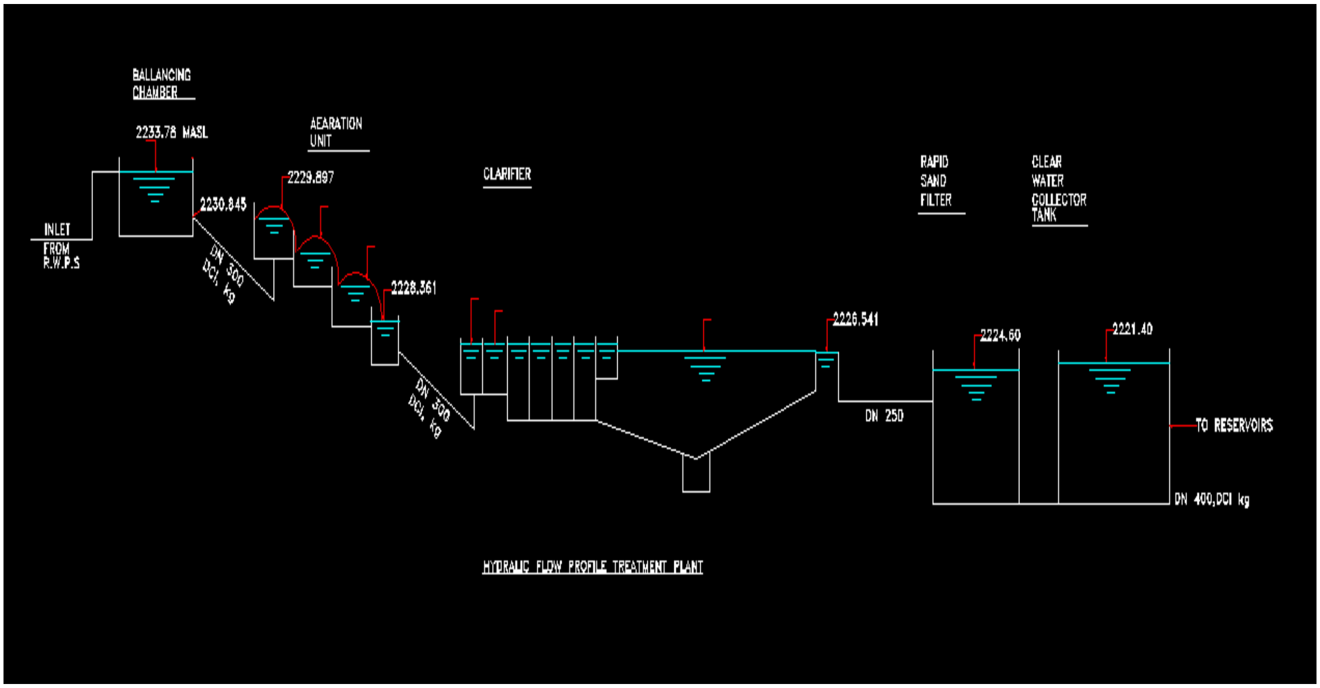


Figure 3.2: Layout of Naqamte WTP

### 3.5.1 Cleaning of treatment plant units

All treatment plant units need proper cleaning to completely remove the sludge or settled particles during the treatment process. Waste water disposal piping system for the treatment plant units has been provided. The balancing chamber which its location is inside the treatment plant compound and aeration (cascade) are integrated in the disposal piping system.


Figure 3.3: Aeration (cascade) (photo taken on 2 August, 2019)

## 3.6 Research design

Research design referred to as a master plan, blueprint, and even a sequence of research tasks. Hence, this study is exploratory, descriptive, and applied study. Therefore, the required activities are shown as a flow diagram below:

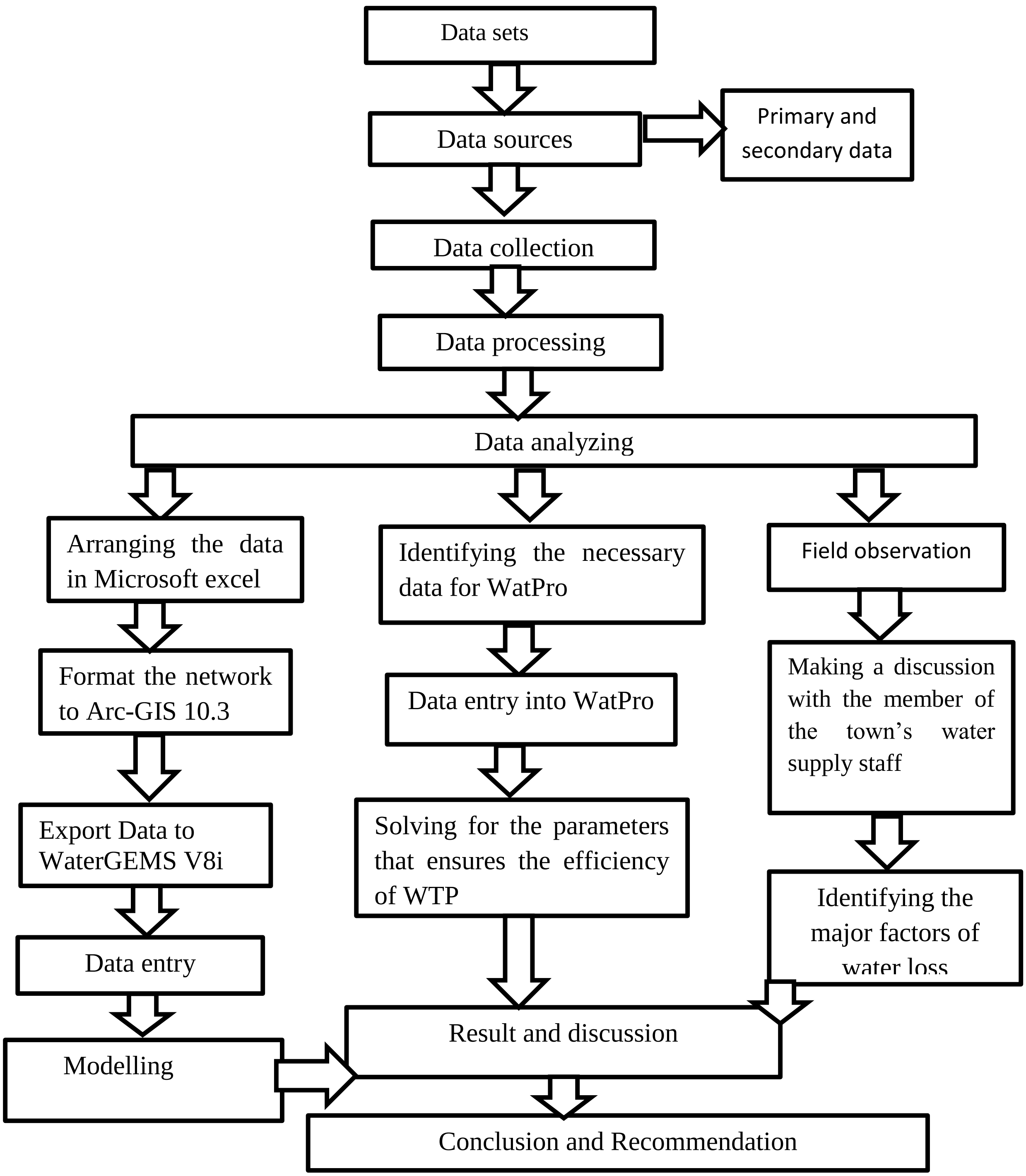


Figure 3.4: Flow diagram of the study

## 3.7 Data sources

The source of data was involved both primary and secondary data. For this study, the primary data were obtained from pressure reading, elevation surveying and some important information was gathered from the existing town water supply services by dealing negotiation with water utility staff members to gain additional relevant information on the subject matter. While, secondary data were collected from different literature reviews, design report, the town water supply service office, existing documents and annual reported papers.

## 3.8 Data collection

Data collection is the most significant part in research work. In order to accomplish this work, the data were gathered with regard to the necessary input parameters of model simulation, water losses and leakage management trend in the system. The data collection techniques were carried out through field visit to Naqamte town on August 10, 2019. Hence, method of data collection for this study was accomplished via field observation. Data were obtained from design report of existing town water supply system, town water service office, DH consultant, and field observation.

## 3.9 Data processing

Data process is the way in which data collected (raw data) is interpreted into result (readable format) or the allocated data achieve its goal to accomplish the work of the study. Data gathered from both primary and secondary were processed through observation in order to bring up the results of the study or arranging the data for analysis purpose.

## 3.10 Method of data analysis

The processed data were analyzed by the two method of data analysis (qualitatively and quantitatively). Thus, quantitatively data analysis deals with data in the form of number and use mathematical operations to investigate their properties. In contrary, qualitative data analysis mostly based on the data expressed in the form of words: descriptions, accounts, opinion, feelings, and the process of investigation will be more tentative and explorative than in quantitative research.

## 3.11 Materials and Tools

The tools used during the study were, Geographical Positioning System (GPS 64) was used to collect the required elevation data during pressure reading. But, Most of elevation data was obtained from the town water service office which was prepared as the design report of

Naqamte town water supply system (existing document). Pressure readings were done using pressure gauge which is commonly taken in the selected points of distribution system.

In addition to this tool there are some programs which was carried out. Thus, ArcGIS 10.3 was used to display the overlapped shape file of the distribution network on the topographic map of the town. While, Microsoft Excel sheet were used to organize elevation data, to calculate a repeated work of nodal base water demand requirement of distribution network simulation and for manual pressure validation work.

## 3.12 Pressure Criteria

The design criteria used in the design of pressure zone boundaries, nodal pressure during the period of peak demand, and optimum velocities of the transfer and distribution mains are as follows: The operating pressures in the distribution network according to MoWR Urban Water Supply Design Criterion shall be 15m to 80 ranges. 1) 85% of field test measurements should be within ± 0.5 m or ± 5% of the maximum head loss across the system, whichever is greater. 2) 95% of field test measurements should be within ± 0.75 m or ± 7.5 % of the maximum head loss across the system, whichever is greater. 3) 100% of field test measurements should be within ± 2 m or ± 15% of the maximum head loss across the system, whichever is greater.

## 3.13 Velocity and Head loss

According to MoWR Urban Water Supply Design Criterion Water velocities shall be maintained at less than 2 m/sec, except in short sections &for pumps. Velocities in small diameter pipes (<DN100) may need even lower limiting velocities. A minimum velocity of 0.3 m/sec can be taken, but for looped systems there are also pipelines with sections having velocity <0.1m/sec. Head loss is related to velocity and pipe roughness. The maximum head loss with therefore be governed by the maximum velocity criterion. Experience shows that a pipe designed to flow at a velocity between 0.6 and 2 m/sec, depending on diameter, is usually at optimum condition (head loss versus cost). Short sections, particularly at special cases, e.g. at inlet and outlet of pumps, may be designed for higher velocities. Minimum static head is 20 m, which can supply a 4-storey building from the distribution system. Maximum static head within a pressure zone was limited to 80 m. Minimum dynamic head was established at 10 m. Maximum velocities of major transmission mains < 2.5 m/s.

Maximum velocities of distribution mains < 2 m/s. Minimum velocities range 0.1-0.3 m/s within the system.

## 3.14 Building a model using model builder

For model building the Arc GIS exports data to excel then digitize all the network and change the file to the shape file, then WaterGEMS using model builder interface imports directly the shape files at ones file is exported to Arc GIS.

In the Model Builder, one can select the 'data source type' as shape files, and the very important aspect that the user has to consider during modeling is that all the data files used during modeling should have the same geographic projection.

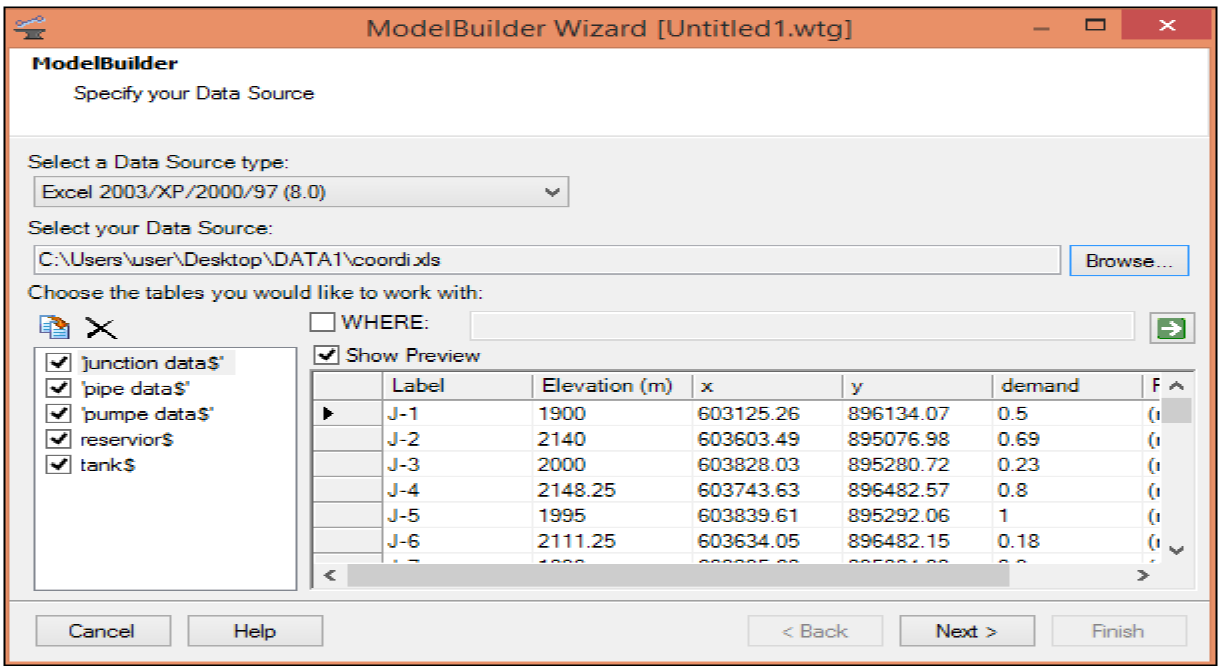


Figure 3.5: Building a model via importing excel data

The shape files of the water lines, appurtenances, reservoirs and the storage facilities were projected with respect to the coordinate system of WGS. Once the shape files are selected the user can preview the attribute tables of each shape file. Next the user needs to specify the co-ordinate unit of the data source. The co-ordinate unit selected was 'meters'. The Model Builder then executes the build operations evaluating the user defined conditions. Once the model has been built, the user has to edit the network. For each specified field mapping should accomplished.

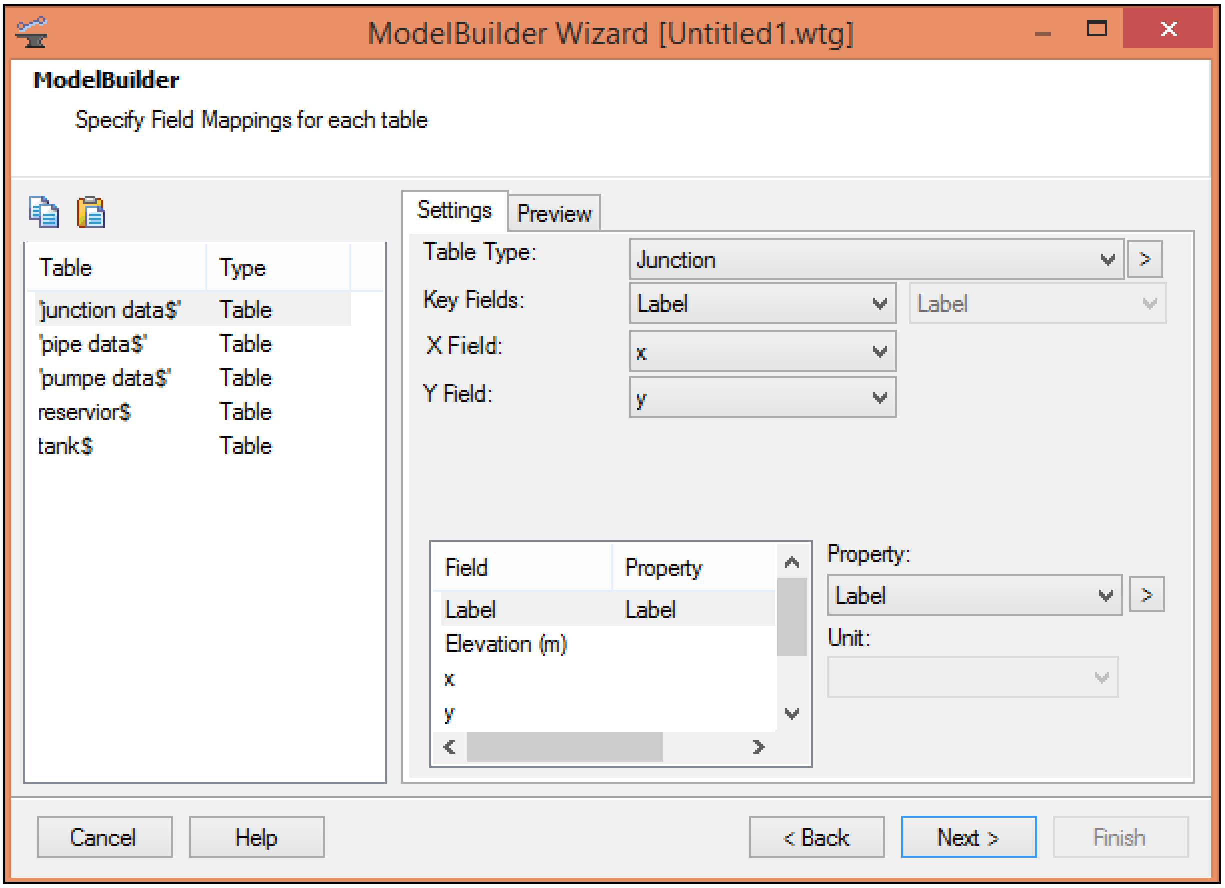


Figure 3.6: Model builder field mapping

## 3.15 Hydraulic Model: Water GEMs

Water GEMS is a comprehensive and easy to use water distribution modeling application and it is more efficient and changes can be done very easily. Water Gems is also a versatile hydraulic modeling software package with the advancements in the interoperability, optimization of networks; model building supported with geospatial tools and asset management tools and tracks the flow of water in each pipe, the pressure at each junction, the height of water in each tank, and the concentration of water throughout the network during a simulation period.

In order to assess the hydraulic performance of the distribution network some parameters were required like flow velocity, pressure and etc. The analysis is beginning by feeding the diameter of distribution pipes in to software and the pressure, velocity and head loss are in the distribution system. Pressures were measured throughout the water distribution system to monitor the level of service and to collect data for use in calibration.

Pressure readings are commonly taken at water distribution mains also at hose bibs, and home faucets (Bentley, 2008). The method of pressure readings were done using pressure gauge. As per Benyam, (2016) and Tomas, *et al.*, (2003); in water distribution networks the most basic type of mode simulations are either steady-state or extended-period simulation.

**Steady-state simulations:** represent a particular view of point in time and are used to determine the operating behavior of a system under static conditions. It compute the hydraulic parameters such as flows, pressures, pump operating characteristics, and others by assuming that demands and boundary conditions were not change with respect to time.

**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. In general, this type of analysis was used to determining the short-term effect of demand conditions on the system (Tomas, *et al*., 2003 and Benyam, 2016). Hence, this study was used the steady state simulation and Extended period simulation for the work in order to accomplish the study. For this study WaterGEMS V8i is used because: it modifies the flex table, analyze pipe and valve criticality, identify leakage and water loss from the network, prioritize pipe renewal, build and manage hydraulic models, manage energy use can effectively identify potential problem areas.

### 3.15.1 Modeling scenarios

One of the many project tools in Bentley WaterGEMs V8*i* is Scenario Management. Scenarios allow you to calculate multiple "What If?" situations in a single project file. You may wish to try several designs and compare the results, or analyze an existing system using several different demand alternatives and compare the resulting system pressures.

A Scenario is a set of Alternatives, while alternatives are groups of actual model data. Scenario and alternatives are based on a parent/child relationship where a child scenario or alternative inherits data from the parent scenario or alternative.

The water distribution network in the continuous supply systems should be designed to with stands the range of pressures corresponding to the minimum and maximum supply conditions.

Which means: at (average day demand (base demand), peak hour demand & low flow demand, (night flow demand). Here are sample Scenarios & Alternatives for Study the System.

i) Steady State Simulation Average daily demand alternatives as base scenario. ii) Extended Period Simulation -Peak hour demand as child scenario iii) Future Water requirement is checked for, 2035.

### 3.15.2 Model calibration and validation

It is the fact that the computed parameters of the model and real field measurement are not usually has the same result. Hence, Calibration was carried out i.e. is a process of adjusting the model input data until its results become closely approximate to the measured field data. In order to calibrate and validate the hydraulic network and for comparison purposes, some quantitative information is required to measure model performance.

In this study, the pressure data measured was used to evaluate the model performance. The method of pressure readings was done during Sept 20, 2019 using pressure gauge commonly taken both at higher and lower zone of the selected points in distribution network; such as raw water pump stations, service reservoir, public fountains and different end user taps (like; customers, institution and commercial tap points). These observed pressure data was taken a total of ten (10) samples for peak demand time analysis. Five samples was taken from lower zone and five samples from higher zone. All sampling points were selected after the computed model was simulated and knowing the pressure variation area (pressure zone) in the town water distribution network. The model validation work was taken by comparing the measured pressure and computed values. Therefore, correlation ($R^2$) was used to check that the model is validated by using Microsoft Excel sheet.

According to Benyam, (2016) and Tomas, *et al*., (2003), the calibration process was performed by adjusting sensitive parameters related with flow; like pipe roughness coefficient and water demand until it was become within the acceptable limit of 85% of field test measurements (it should be within $\pm$0.5 m or $\pm$5% of the maximum head loss across the system, whichever is greater).

Hence, as per pressure criteria 85% of the computed model results should become within ±0.5m head of the observed field conditions. Hence to assure the acceptable level of calibration, the two most commonly used model inputs parameters; pipe roughness coefficients and junction demand data were adjusted. Hence, during model calibration; C-factor was used 150 for PVC, 120 for HDPE and average value of 130 for DCI pipe.

Accordingly, demand adjustment was undertaken by adopting multiplier factors in reasonable way (a maximum and minimum of 1 and 0.2, respectively) and demand concentration also adjusted based on actual condition of the town. With regard to these, time series representations of the calibrated pressure head difference were presented as (annex-E) and (annex-F)

## 3.16 Water treatment simulation: WatPro

WatPro is a useful program for analyzing and designing a water treatment system. With this program, an engineer can create a simulation of a water treatment plant and predict water quality given specific parameters. It is a steady-state water treatment modeling program, with a focus on disinfection and disinfection by-products.

Although other aspects of water treatment processes are supported, these are of lesser significance within the package's scope. The information in this section is taken from the WatPro User Guide (Hydromantis, 2004).

WatPro 4.0 used raw water quality parameters to simulate water treatment i.e. pH, turbidity, residual chlorine, and chemical dosages (e.g., alum, ferric chloride, lime , ammonia) and design and operating characteristics of process tanks, WatPro accurately simulates plant operation.

WatPro was required for simulation of water treatment to: identify the formation of DBPs (e.g. THMs, HAAs, chlorite, chlorate, calculate contact time (Ct) for any location in the treatment system, and compare inactivation of viruses and Giardia by chlorine, ozone, chlorine dioxide and chloramines.

### 3.16.1 Data needed for plant simulation

The necessary data that are required for drinking water treatment simulation are: characteristics of water, water treatment plant layout, chemicals to be added and the like.

Those data was obtained from the office of Naqamte town water supply office and used as an input for WatPro. The other data like water quality (PH, turbidity, residual chlorine, etc) were taken from the laboratory technician of the town's water supply. According to the Naqamte town water service office there is no sufficient laboratory equipment for the analysis of DBPs (TTHMs, HAA5s, chromite and the like) and no giardia and viruses problem occurred out there. However, this study was identified the existence of disinfection by-product and giardia and viruses by Watpro 4.0, using the data obtained from the Naqamte town water service office.

In general, concerning the raw data entry for this WatPro was accomplished by obtaining from Naqamte town water service office and laboratory output from the laboratory technician.

### 3.16.2 Simulation and Evaluation of Disinfection Processes

A water treatment simulation has been established for the disinfection (Chlorination) process in water treatment Plant of the town. The simulation of chlorination has been performed using the water treatment simulator WatPro 4.0 software (Hydromantic) free trial version. As explained under section (3.11.1) the water quality parameters and other data has been taken from Naqamte water supply service office and laboratory technician. Three inactivation parameters have been designated by the simulator software to assess the disinfection accomplishment: total giardia reduction, total virus reduction, total crypto reduction. The advantages of simulation analysis are obtaining a useful method to establish a broad understanding of the operating performance of the disinfection process. The quality of effluent treated water quality was employed to determine differences in water quality among the three processes. DBPs (THM and HAA) formation potentials in water effluents were used to discover the convenience of each disinfection process.

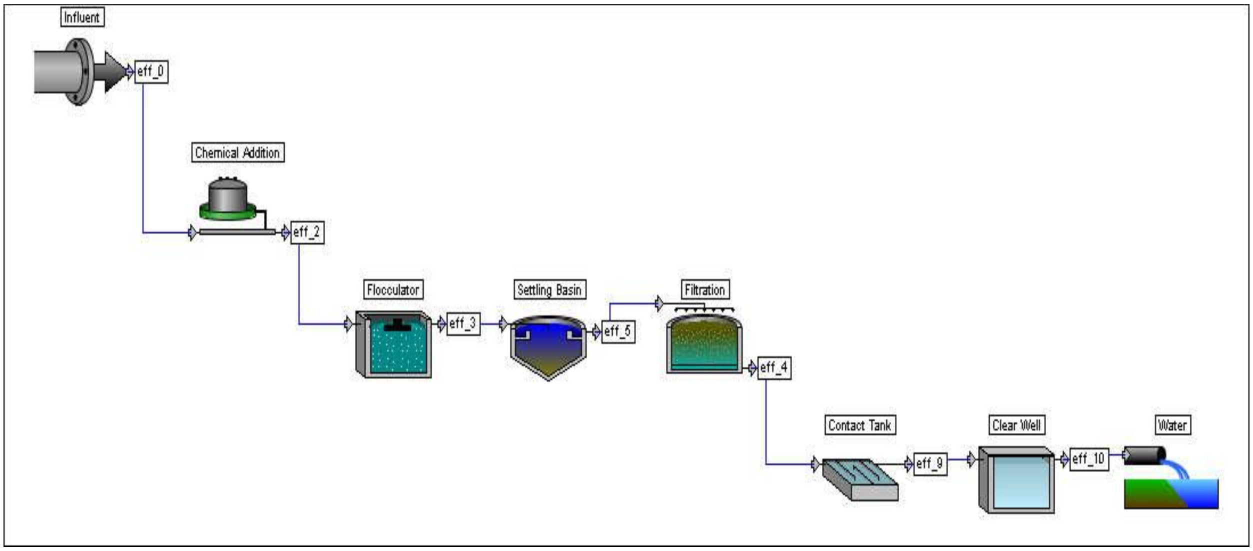


Figure 3.7: Process flow diagram of the NWTP using chlorination

## 3.17 Estimated water demand of the town

Estimating the expected water demand of the town were used for evaluating and sizing of water distribution network components.

### 3.17.1 Population projection

The water demand of a particular town is proportionally related with the population to be served. The population of Naqamte town from Ethiopian CSA report, which is carried out in year 2003, was indicated 68,790 and it was used as base population for current estimation. Therefore, considering the 2003 population as a base population figure since this figure had been found CSA population data for same year and adopting the growth rate recommended by the same authority to calculate population projection of urban towns in Oromiya region from year 2003 up to year 2035. According to the population of Naqamte town in 2003 up to 2035 as projected population count was adopted by Naqamte town administration office; Whereas using the population census and applying the recommended urban growth rate of 4.11%, is used for checking.

Using the above CSA (2003) census data as a base, applying exponential population forecasting method, the current (2019) estimated population figure for Naqamte town was presented in Table 4.1

$$Pn = Po * e^{r*n} \tag{3.2}$$

Where: $P_n$ = Estimated population

$P_o$ = Base population figure

$r$ = Growth rate and,

$n$ = Number of year

Hence, considering the above equation 3.2, the estimated total population figure of Naqamte town was 137,171 during 2018 year and taking this estimated number of population as the current population, the following parameters would be computed:

### 3.17.2 per capital water consumption

The per-capita water consumption for various demand categories varies depending on the size of the town and the level of development. In Naqamte, because of the growth of the socio-economic activity in both governmental and private sectors, there was the high water demand in the town. Using the annual water consumption and population figure in (2019), the average per capital consumption of the town was identified as below.

Per capita consumption (l/c/d) = Annual consumption ($m^3$ * 1000l/$m^3$) / population figure * 365 (3.2)

### 3.17.3 Average water demand

There are several mathematical methods of estimating the water demands of a given town; including extrapolating historical trends and correlating demand with the socio-economic variables of the town. But, the most common means of forecasting future water demand is estimating current per-capital water consumption, and multiply this by the projected population figure. Hence, during 2019 the average water demand for Naqamte town was computed as:

$Q_{av}$ = no population * per capita water consumption (3.3)

### 3.17.4 Peak hour demand

The maximum flow rate delivered by the distribution system on any single hour during the year corresponds to the peak hour water demand. As per the Naqamte water supply office, PHD typically occur during the morning and evening hours. In relation to the population size the recommended peak hour factor is 1.6 (from Table 2.2). Hence, the Peak Hour Demand is computed as follow;

Peak hour demand = PF * $Q_{av}$ (3.4)

## 3.18 Hydraulic performance analysis of the distribution system

### 3.18.1 Existing service reservoirs

Service Reservoir is a storage facility that is designed to: equalize the hourly fluctuation of flow, make uniform pumping rate possible, provide uniform water pressure, and reduce operating cost by operating pumps at the rate for the maximum efficiency. In addition it serves as source of water for firefighting. The most appropriate and economical approach of determining storage volume of reservoir is the 24 hours supply demand simulation mass curves. In order to develop such type of curves, it requires reliable recorded historical data of hourly water demand figures of the town. But, in the absence of such type of data, to determine the size of reservoirs, it was adopted the commonly practiced in many water supply systems and based on the urban water supply design criteria of the ministry of water resources; it was used for sizing the reservoir volume as one third of the maximum daily demand. Therefore, as per the design criteria of the FDRE; MoWIE, 2009, the maximum day factor usually varies between 1.0 and 1.3. Hence, a maximum day factor of 1.2 was adopted for evaluating the maximum day water demand and reservoirs capacity for Naqamte town and applied it corresponding to the total average day demand of a particular year (2019).

$$\text{Max.day demand} = 1.2 * \text{average day demand} \tag{3.5}$$

Therefore, the current (2019) required service reservoirs volume capacity for water demand of Naqamte town was computed as:

$$\text{Reservoir capacity} = Q_{max} * 1/3 \tag{3.6}$$

### 3.18.2 Pump capacity

One of the main components of water distribution systems is the pump stations. Pumps were deliver energy to the hydraulic system in order to overcome elevation difference and head losses due to pipe friction and fittings. Pump head curve is one of the necessary input parameters for water distribution modeling and according to Tomas, et al., (2003) and Benyam, (2016), is an energy equation which used for solving pipe network problems. For this study, raw water pump efficiency were conducted in order to determine the pumps capacity. Therefore, using the finding (Annexes-G); the efficiency were assessed manually and computed as below;

$$\text{Pump Efficiency} = \text{Water Power}_{\text{out, maximum}} / \text{Pump Power}_{\text{in}} \tag{3.7}$$

According to the computed WaterGEMS model outputs (Annexes-G) and information obtained from Naqamte Town Water Service Office; those pumps performing in the system were operating for 24 hours in a day. With this the pumps maximum capacity of delivering water to the distribution system was discussed as:

$$\text{Pump capacity} = \text{pump design capacity} * \text{effective pump operation time} \quad (3.8)$$

## 3.19 Evaluation of water treatment plant's major unit processes capability

The major unit processes included flocculation, sedimentation, filtration and disinfection units. Hence, the capabilities of major unit processes were determined by using the following formulas:

a) $\text{Flocculation basin capability} = \frac{\text{Basin volume(m3)}}{\text{Detention time (min)}}$ (3.9)

b) Sedimentation basin capability = Basin surface area ($m^2$) * surface over flow rate (3.10)

c) Filtration basin capability = Filter bed area ($m^2$) * Filter loading rate ($l/min/m^2$) (3.11)

The rated capability of the three filtration units was determined by assuming one of the filters out of service for cleaning.

d) Chlorine contact time: To inactivate viruses and bacteria using free chlorine, the disinfection treatment required before the first customer must be evaluated. As per the result obtained from laboratory expert of water quality of Naqamte water supply, the water at the entry point to the distribution system has a free chlorine residual of 1.6 mg/L and the chlorine is in contact with the water for 3 minutes between chlorine injection and entry point to the distribution system, CT is computed as follow:

CT = Concentration of free chlorine ($C_{mg/L}$) * contact time ($T_{minutes}$) (3.12)

e) Contact tank

The effective contact time is related to both the volume of the contact tank and its design/structure. In the absence of any tracer test data for the tank, the effective contact time can be estimated from:

Effective contact time (minutes) = tank volume ($m^3$) x 60 x Df / flow ($m^3/h$) (3.13)

DF is a factor related to the efficiency of the system to minimize short circuiting through the tank.

Table 3.7: Baffling conditions with its baffling factors

| **Condition** | **Description** | **Df** |
|---|---|---|
| Unbaffled | None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities. | 0.1 |
| Poor | Single or multiple unbaffled inlets and outlets, no intra-basin baffles. | 0.3 |
| Average | Baffled inlet or outlet with some intra-basin baffles. | 0.5 |
| Superior | Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders. | 0.7 |

(Source: EPA, water treatment manual; disinfection, 2011)

## 3.20 Evaluation of contact time for water system

Contact time is a measurement of the length of time it takes for chlorine (most commonly used water treatment disinfectant) or other disinfectants to kill giardia at a given disinfectant concentration. An operator measures the amount of contact time available at the plant before the water goes out to the public to ensure that 99.9% of giardia is either removed with filtration or inactivated with chlorine before the water gets to the public.

As per the Naqamte Water Supply Service Office no measurements has been taken for the CT evaluation of the water system. However, this study tried to confirm the evaluation of CT for water supply system of the town by the following steps;

Step 1: Determine the time available in the basin at peak flow

$$\text{Time(min)} = \frac{\text{basin volume (m3)} * \text{baffling factor}}{\text{peak hourly flow } (^{\text{m3}}/_{\text{min}})} \quad (3.14)$$

Step 2: Determine the contact time available at peak flow

Available contact time (min mg/l) = Time (min) * chlorine concentration (mg/l) (3.15)

Step 3: Find the required Contact Time (CT) from the tables at peak flow

Determine the CT required by the Environmental Protection Agency. By looking up the CT from the CT tables provided in the EPA of the Guidance Manual using the measurements that has been taken from the water quality expert; 6.5 of PH, 20$^o$c of temperature and 1.6 of chlorine concentration i.e. from annex-D.

Step 4: Does your water system meet CT requirements?

Compute the inactivation ratio by dividing the actual contact time by required contact time. If the ratio is greater than 1, then the water system met its contact time requirements.

$$\text{Inactivation ratio} = \frac{\text{Actual contact time}}{\text{required contact time}} \qquad (3.16)$$

(3.16)

## 3.21 Evaluation of existing plant efficiency

Most importantly, it is wise to verify if the treatment and supply systems are efficiently performing their objectives. The core purpose of the system is to produce at least 99 l/s of clean water as given in the design report. Thus, 99 l/s = 356.4 $m^3$/hr or 8,553.6 $m^3$/day. But it is identified that current practical operation works at 170 x 1 pump = 170$m^3$/hr or 4,080 $m^3$/day.

Note that it doesn't bring any difference if it starts 2 sets of raw water pumps because due to the dissolved iron and manganese as well as other organic constituents in the raw water, it cannot expect capacity of the clarifiers to hold more than this.

But, only 2,846 $m^3$ of clean water every day in the distribution system (the current plant capacity). However, the treatment plant efficiency of the town can be estimated as below;

$$\text{plant efficiency rate} = \frac{\text{water consumed}}{\text{water produced}} * 100 \qquad (3.17)$$

# CHAPTER FOUR

# RESULTS AND DISCUSSIONS

## 4.1 Population projection

As per the information suggested under section (3.1.1) and equation (3.2) of chapter three, the current number of population of the town is 137,171. This shows that there was no balance between the current water demand of the town and the current number of population. So that there was scarcity of drinking water in the town since water supply system accomplished intermittently (discontinuously). Therefore, Naqamte town population projection from year (2003-2035) was tabulated in the following Table 4.1:

Table 4.1: Naqamte town estimated population

| Description | Unit | Projected population | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | | 2003 | 2008 | 20013 | 2018 | 2023 | 2028 | 2035 |
| population | No | 68,790 | 88,244 | 110,601 | 137,171 | 168,339 | 204,122 | 260,460 |

### 4.1.1 per capital water consumption

The computed result under equation (3.2), describes that the per capita water consumption of the town was 20.9 l/c/d. But in contrarily, as per the existing town water supply design report, the average per capita water demand of the town at the end of the design period (2008) was estimated and adopted as 25-30 l/c/d. With the comparison of this figure the above estimated per capital consumption value 20.9 l/c/d was unrealistic and unacceptable. Hence, it was not adopted for this evaluating work.

Therefore, further reviewing work was necessary to fix the recent per capital water consumption of the town. As per the World Health Organization (WHO, 2010), between 50-100 l/c/d are needed to ensure that most basic needs are met and few health concern arise. Hence, the computed and design report was complies with standards.

### 4.1.2 Average water demand

As per the equation (3.3), the result of average daily water demand of Naqamte town was 10,287.8 $m^3$/d. This result shows that the average daily water demand of the town is the sum of domestic and non-domestic water demand.

Average water demand was mainly depends on the general behavior of people, climatic conditions and character of city as industrial, commercial or residential. Hence, the current average water demand was not sufficient for domestic and non-domestic water demand of the town.

### 4.1.3 Peak hour demand

Referring to equation (3.4), the result of peak hour demand of the town was 16,460.4 $m^3$/d. This mean that people of the town uses 16,460.4 $m^3$/d of water at peak hour. According to Naqamte water supply service office, maximum hour water demand is happen during morning and evening time over 24 hour, because in these time most people use water for bathing, washing and cooking purpose. The peak hour demand is the highest demand of any one hour over the maximum day. It represents the daily variations in water demand resulting from the behavioral patterns of the local population. Experience clearly demonstrates that the peak hour factor is greater for a smaller population. Hence, this peak hour demand result did not matched with that of the growing population of the town.

### 4.1.4 Forecasting water requirements

Depending on the population figure result tabulated in Table 4.1, the forecasted water demand for each number of population was computed as follow;

Table 4.2: Forecasted water demand of the town

| No | **Description** | Unit/year | 2018 | 2023 | 2025 | 2030 | 2035 |
|---|---|---|---|---|---|---|---|
| 1 | Avg. Day Demand | $m^3$/d | 10,287.8 | 10,235 | 17,377 | 24,480 | 32,608 |
| 2 | Max Day Demand | m3/d | 12,345.36 | 13,939 | 23,460 | 33,048 | 44,020 |
| 3 | Peak Hour Demand | m3/d | 16,460.4 | 17,036 | 28,673 | 40,392 | 53,803 |

## 4.2 Hydraulic performance of the distribution system

### 4.2.1 Existing service reservoirs

As the result of equation (3.5) and (3.6), shows that the current reservoir capacity of the town was 4115 $m^3$/d. Thus, this result was far away from the existing service reservoir capacity of the town mean that the finding and the existing capacity did not matched to each other.

But, in the existing water supply system of Naqamte, both lower and upper zone of service reservoir had a capacity of 2500 $m^3$. This indicate, the existing service reservoirs capacities were not big enough in size comparing with the current water demand of the town. Hence, the current service reservoirs are not in good capacity to deliver adequate water to the distribution network in order to meet the current water demand of the town.

Figure 4.1: The existing service reservoirs (Source: field observation, August, 2019)

### 4.2.2 Pump capacity

The developed pump head curve during model simulation work were presented as figure 4.2 below.

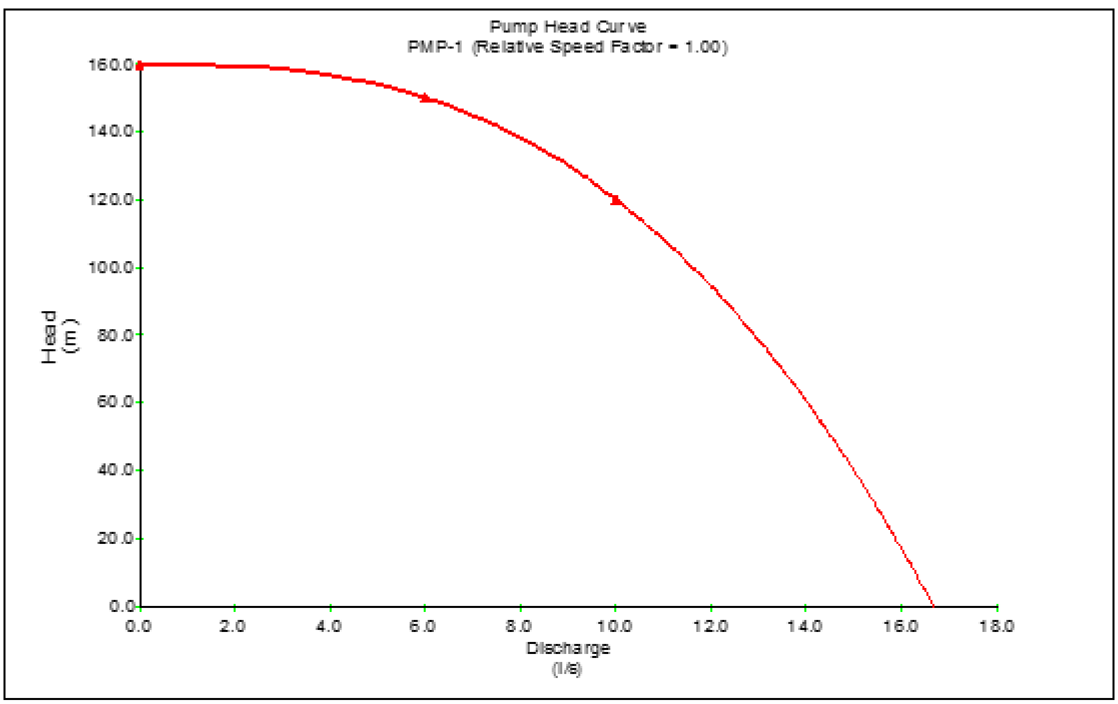


Figure 4.2: Raw water pump

According to field observed data and model simulated result (annexes- G); the pump brake horse power and maximum water power were collected as 59 kW and 31.2 kW, respectively. Accordingly, the pump efficiency was 52.8%, which complies with ISO 9906; 2012 (Benyam, 2016). However, pumps that perform in good condition have efficiency in the rank of 60-80% (ISO 9906; 2012). Hence, a lot of factors like damages of pumps and frequent failure, the pump was not replaced for a long time are occurring, thus the pumps did not perform within the required efficiency range.

Therefore, the 52.8% of the pump efficiency was shows that currently those pumps were not operating in good performance and did not deliver sufficient water to treatment plant continuously.

Referring to the equation (3.8), the existing raw water pump capacity was 2,851.2 $m^3/d$, mean that such amount of maximum water were delivered to the system. However, from equation (3.5), the current maximum water demand of the town is 12,345.36 $m^3/d$, and this indicates that the raw water pumps capacity were not met the current water demands of Naqamte town.

### 4.2.3 Distribution main lines

Concerning the landscape of Naqamte town, the locations of nodes in the water distribution line is in close proximity to each other. The maximum and minimum water pressure in the distribution system was 185.45 and 5.14 m head around treatment plant and service reservoir, respectively.

According to the design criteria of the FDRE; MoWIE, the maximum and minimum water pressure in the distribution system is 80m and 15m, respectively. Beside these comparisons; the current Naqamte town existing water distribution network was operating out of the recommended limitation. This is because of; water was delivered to the distribution main by gravity means, and the system were served beyond its design life.

### 4.2.4 Pressure in the distribution system

Variation of water pressure in the distribution system is mainly because of hourly fluctuation of water demand. As shown in Figure 4.3; the water pressures in the water distribution system were a function of this factor (hourly fluctuation of water demand).

Variation of elevation difference in most part of the town has also an impact for the rising and reduction of water pressure in the network. Therefore, during peak demand time most part of the network was disconnected from the system and wide residential area of the town were not getting water. While, most of the residences were get and collect water at night flow during low demand time.

However, residences found around treatment plant area, downstream of treatment plant and lower part of the town get water continuously (without any intermittent).

### 4.2.4.1 Negative pressure

The condition that give rise to negative pressures should always be avoided. Hence, negative pressure in the distribution system is one of the factors for intermittent water supply.

This negative pressure in distribution network has a great impact on the life cycle of population by degrading the economic growth of the town in terms of investment, rising conflict among the society and etc. For this study, all negative pressure presented in (Annexes-H2) indicates; the system was disconnected during peak demand time (especially morning and evening time), and water was not reaching to customers. Whereby, these was mainly as a result of; there is demand concentration (greater demand than the design demand), inadequate pipe capacity (small diameter), and availability of residences on higher ground of the town.

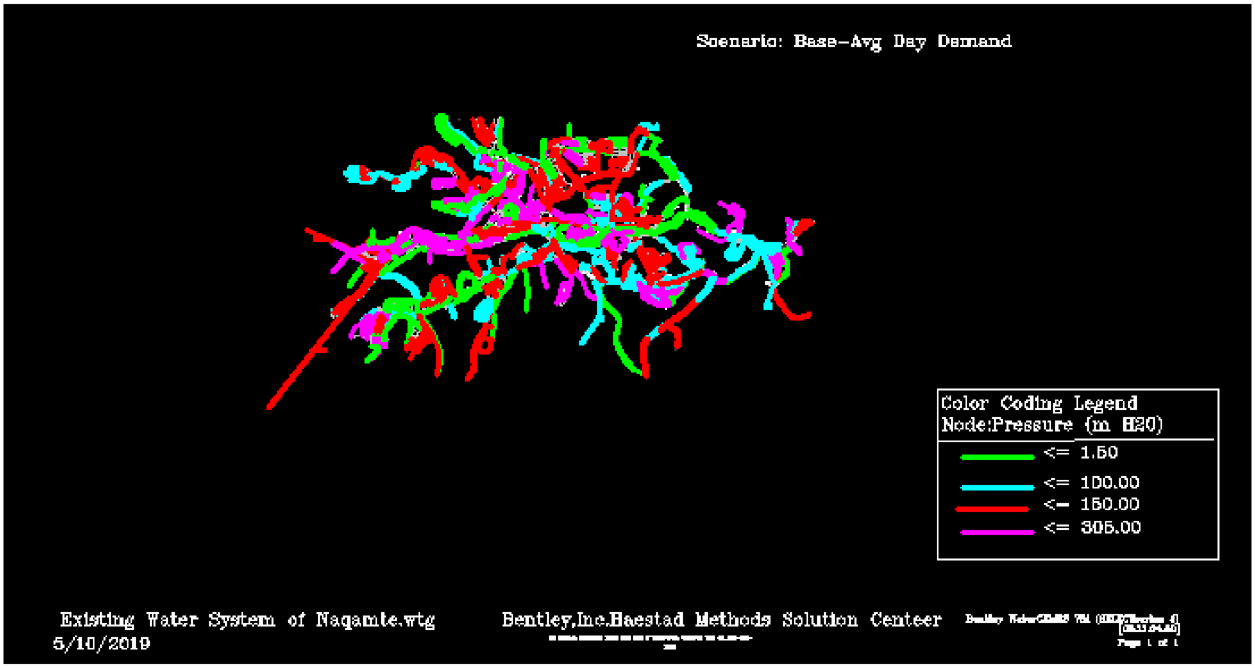


Figure 4.3: Pressure map of nodes for average day demand

### 4.2.4.2 Pressure Zones

Given the topographical layout of Naqamte, and the configuration of the existing distribution network, the task of dividing the study area into pressure zones is one of the significant tasks. Allocating nodes to their appropriate pressure zoning would give the chance to the nodes getting better flow and pressure head. As a result, the system shows better improvement. Construction of a workable model to simulate the town’s distribution system, creating a key tool for its operation and management. In the pressure zoning, the software WaterGEMS is highly responsible for categorizing the system. Formulation of a scheme for optimal division of the existing and future network into feasible pressure zones complying with sound technical and economic considerations.

Three pressure zones (normal, high or boosted and low) for Naqamte water system were delineated. Hence, the three pressure zones were colored with different color coding i.e. pressure zone-1 (normal, green color) e.g., Square 1and 2, Kumsa moroda palace, stadium, bus station, around Maryam Orthodox Church, kesso school. Pressure zone-2 (low, red color) e.g., Iyadeg garage, Wallaga university condominium, Oromiya road authority office, Burka Jato, kidanemhiret area, and Pressure zone-3 (high, blue color) e.g., Sorga, Darge, Naqamte hospital, and Wallaga university referral hospital.

Table 4.3: Pressure boundaries of Naqamte town water distribution system

| Pressure Zone | Nodes <count> | Isolation Elements <count> | Pipes <count> | Boundary Pipes <count> | Length (m) | Fluid Volume (L) | Color |
|---|---|---|---|---|---|---|---|
| Pressure Zone-1 | 158 | 19 | 203 | 12 | 42,055 | 46,858,261.50 | |
| Pressure Zone-2 | 42 | 5 | 25 | 0 | 6,023 | 157,648.90 | |
| Pressure Zone-3 | 41 | 3 | 13 | 1 | 4,022 | 124,659.40 | |

The above pressure zones has been clearly delineated by WaterGEMS V8i as below;

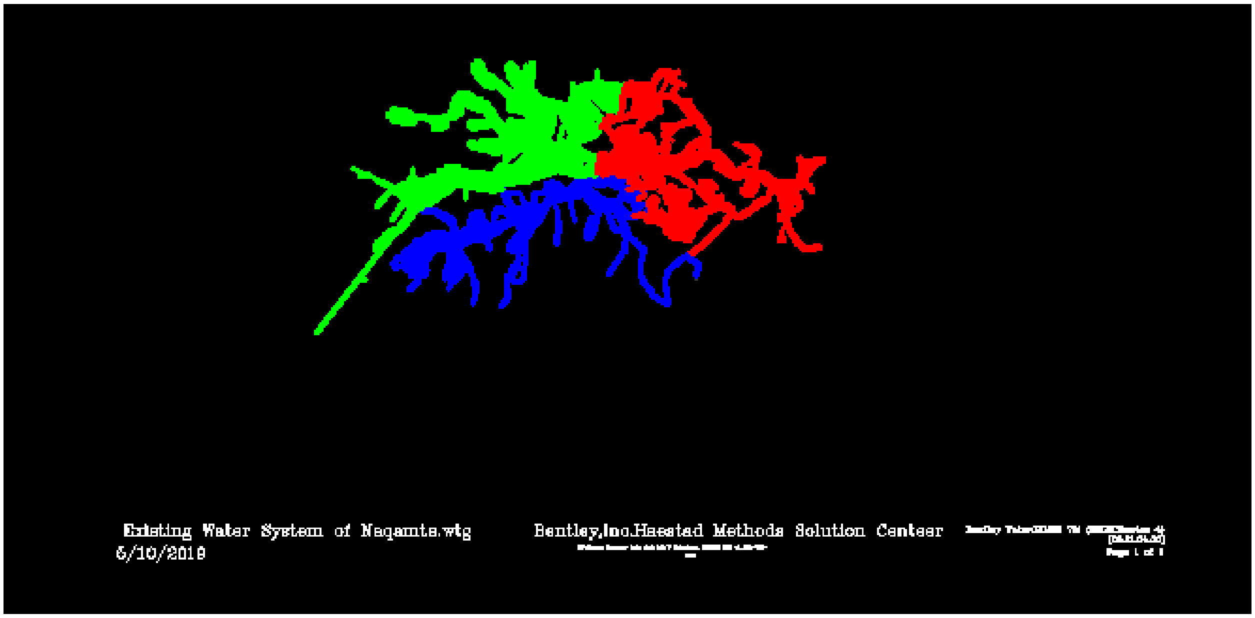


Figure 4.4: Pressure zones

Table 4.4: Nodes having low values of pressure, Steady state Analysis (-5<=P<=10m)

| Label | Elevation (m) | Demand Pattern | Demand (l/s) | Hydraulic Grade (m) | Pressure (m H20) |
|---|---|---|---|---|---|
| J-174 | 2000.00 | | 0.09 | 1860.45 | -3.47 |
| J-148 | 1900.00 | | 0.09 | 1458.72 | -3.4 |
| J-117 | 1800.00 | | 0.23 | 1976.91 | -3.05 |
| J-210 | 1890.00 | Domestic | 0.50 | 1286.80 | -2.77 |
| J-183 | 1995.00 | | 0.14 | 1903.15 | -2.66 |
| J-123 | 2000.00 | | 8.07 | 1726.38 | -2.56 |
| J-140 | 2121.00 | | 0.09 | 1154.93 | -1.84 |
| J-126 | 2115.00 | | 0.16 | 1194.00 | -1.78 |
| J-141 | 2000.00 | Domestic | 0.80 | 1890.68 | -1.74 |
| J-112 | 2100.00 | | 0.14 | 1851.29 | -1.61 |
| J-227 | 1845.00 | | 0.70 | 1981.71 | -1.46 |
| J-214 | 2000.00 | | 0.75 | 1238.58 | -1.39 |
| J-196 | 1900.00 | Domestic | 0.00 | 1913.85 | -0.97 |
| J-239 | 1850.00 | | 0.14 | 1284.27 | -0.91 |
| J-19 | 1995.00 | | 0.14 | 1899.15 | -0.84 |
| J-132 | 2000.00 | | 0.14 | 1469.02 | -0.81 |
| J-233 | 2150.00 | Domestic | 0.25 | 1285.65 | -0.81 |
| J-198 | 1750.00 | | 0.00 | 1685.29 | -0.68 |
| J-219 | 1950.00 | Domestic | 0.80 | 1288.40 | -0.58 |
| J-172 | 2115.00 | | 0.14 | 2127.61 | -0.25 |
| J-138 | 1800.00 | | 0.23 | 1240.64 | -0.21 |
| J-240 | 1750.00 | | 0.75 | 1281.00 | -0.12 |
| J-220 | 1900.00 | | 0.94 | 1287.95 | -0.02 |
| J-202 | 1750.00 | | 0.14 | 1750.20 | 0.20 |
| J-4 | 2148.25 | Domestic | 0.04 | 2378.36 | 0.86 |
| J-85 | 2000.00 | | 0.14 | 2000.89 | 0.89 |
| J-228 | 1800.00 | | 0.50 | 1201.19 | 1.19 |
| J-215 | 1860.00 | | 0.80 | 1201.20 | 1.29 |
| J-216 | 1800.00 | Domestic | 0.05 | 1201.31 | 1.31 |
| J-87 | 2100.00 | | 1.00 | 2331.45 | 1.45 |
| J-11 | 1885.00 | | 0.14 | 2320.96 | 2.11 |

| | | | | | |
|---|---|---|---|---|---|
| J-62 | 2000.00 | | 0.14 | 1202.87 | 2.86 |
| J-214 | 1900.00 | | 0.30 | 1202.78 | 2.77 |
| J-32 | 2040.00 | | 0.14 | 2040.60 | 3.60 |
| J-192 | 1890.00 | | 0.05 | 2105.18 | 5.17 |
| J-224 | 1760.00 | | 0.95 | 1286.71 | 6.7 |
| J-55 | 2000.00 | | 0.09 | 1892.55 | 7.53 |
| J-193 | 1995.00 | | 0.14 | 2107.77 | 7.75 |
| J-97 | 1900.00 | | 0.09 | 2008.45 | 8.44 |
| J-60 | 2105.00 | | 0.09 | 2109.01 | 8.99 |
| J-33 | 1900.00 | | 0.25 | 1899.21 | 9.19 |
| J-197 | 2100.00 | | 0.00 | 2109.34 | 9.32 |

It is obvious from the Table (4.4), that the high values of pressure appear at the nodes nearest to the sources of water (supply point). In contrarily, the low value of pressure at the nodes far away from the supply point), as its shown in the intermittent systems which lead also to conclude that the consumer far away from the supply points will need to be more patient.

Table 4.5: Nodes having high values of pressure, Steady state analysis (80<=P<=304.97m)

| Label | Elevation (m) | Demand Pattern | Demand (l/s) | Hydraulic Grade (m) | Pressure (m H2O) |
|---|---|---|---|---|---|
| J-124 | 2000.00 | | 0.18 | 1480.65 | 80.49 |
| J-14 | 2000.00 | | 0.18 | 1981.39 | 81.22 |
| J-13 | 1900.00 | | 0.16 | 1981.42 | 81.25 |
| J-18 | 2115.00 | Domestic | 0.18 | 1981.49 | 81.32 |
| J-36 | 2000.00 | | 0.09 | 1218.98 | 81.81 |
| J-12 | 2000.00 | Domestic | 0.20 | 1982.06 | 81.90 |
| J-43 | 2000.00 | | 0.14 | 1284.73 | 84.56 |
| J-7 | 1890.00 | | 0.50 | 1284.74 | 84.57 |
| J-45 | 1750.00 | | 0.18 | 1284.88 | 84.71 |
| J-37 | 2000.00 | | 0.18 | 1287.84 | 87.66 |
| J-40 | 1800.00 | | 0.25 | 1285.08 | 84.91 |
| J-232 | 1990.00 | | 0.10 | 1281.56 | 85.15 |
| J-46 | 2100.00 | Domestic | 0.50 | 1290.15 | 89.97 |
| J-26 | 2000.00 | | 0.13 | 1991.27 | 91.09 |
| J-135 | 2000.00 | | 0.18 | 1591.39 | 91.21 |
| J-134 | 1900.00 | Domestic | 0.14 | 1491.40 | 91.22 |
| J-9 | 2100.00 | | 0.08 | 2320.96 | 95.77 |
| J-17 | 1900.00 | | 0.18 | 1296.39 | 96.19 |
| J-34 | 1895.00 | | 0.14 | 1997.27 | 97.07 |
| J-5 | 1995.00 | | 0.50 | 1797.43 | 97.23 |
| J-31 | 1900.00 | | 0.18 | 1897.93 | 97.73 |
| J-169 | 2000.00 | | 0.09 | 1855.60 | 105.39 |
| J-203 | 2000.00 | Domestic | 0.14 | 2106.42 | 106.21 |
| J-130 | 2120.00 | | 0.18 | 2107.66 | 107.44 |
| J-199 | 2000.00 | | 0.14 | 2107.88 | 107.56 |
| J-89 | 2100.00 | | 0.09 | 2208.25 | 108.03 |
| J-63 | 2040.00 | | 0.18 | 1310.47 | 110.25 |
| J-163 | 2140.00 | | 0.14 | 1334.46 | 134.19 |
| J-207 | 2100.00 | Domestic | 0.50 | 2045.55 | 145.25 |
| J-64 | 2000.00 | Domestic | 0.14 | 1346.99 | 146.70 |
| J-154 | 1885.00 | | 0.14 | 1852.61 | 152.31 |
| J-144 | 2115.00 | | 0.18 | 1459.98 | 159.66 |
| J-83 | 2000.00 | | 0.14 | 1364.47 | 164.14 |
| J-121 | 2000.00 | | 0.16 | 1870.88 | 170.53 |
| J-116 | 1800.00 | Domestic | 0.13 | 1984.29 | 183.92 |

| | | | | | |
|---|---|---|---|---|---|
| J-105 | 1885.00 | | 0.09 | 2198.72 | 198.32 |
| J-151 | 1900.00 | | 0.05 | 1925.34 | 205.15 |
| J-200 | 1900.00 | | 0.14 | 2106.27 | 205.86 |
| J-231 | 2100.00 | | 0.07 | 1285.24 | 210.05 |
| J-162 | 2000.00 | | 0.14 | 1334.64 | 210.18 |
| J-145 | 2100.00 | | 0.23 | 1481.73 | 281.17 |

Table 4.6: Links having velocity less than 0.1 m/s

| Label | Diameter (mm) | Material | Hazen-Williams-C | Flow (l/s) | Velocity (m/s) |
|---|---|---|---|---|---|
| P-33 | 500.00 | DCI | 130 | 14.26 | 0.00 |
| P-42 | 300.00 | HDPE | 120 | -2.38 | 0.00 |
| P-69 | 150.00 | PVC | 150 | 12.36 | 0.00 |
| P-87 | 100.00 | HDPE | 120 | 2.99 | 0.00 |
| P-135 | 250.00 | PVC | 150 | 10.96 | 0.00 |
| P-149 | 150.00 | HDPE | 120 | 1.56 | 0.00 |
| P-153 | 400.00 | DCI | 130 | 10.86 | 0.00 |
| P-178 | 250.00 | PVC | 150 | -10.07 | 0.00 |
| P-277 | 200.00 | PVC | 150 | 4.06 | 0.00 |
| P-280 | 200.00 | PVC | 150 | -1.10 | 0.00 |
| P-283 | 200.00 | PVC | 150 | 5.45 | 0.00 |
| P-299 | 200.00 | PVC | 150 | -0.003 | 0.00 |
| P-310 | 150.00 | PVC | 150 | -0.25 | 0.00 |
| P-314 | 150.00 | HDPE | 120 | 1.57 | 0.00 |
| P-249 | 80.00 | HDPE | 120 | 2.5 | 0.001 |
| P-53 | 80.00 | PVC | 150 | -0.32 | 0.003 |
| P-117 | 150.00 | HDPE | 120 | 10.63 | 0.004 |
| P-165 | 200.00 | PVC | 150 | 10.25 | 0.005 |
| P-320 | 150.00 | HDPE | 120 | 0.26 | 0.005 |
| P-106 | 100.00 | PVC | 150 | 10.26 | 0.007 |
| P-99 | 250.00 | PVC | 150 | 8.25 | 0.008 |
| P-276 | 200.00 | PVC | 150 | 1.66 | 0.009 |
| P-10 | 100.00 | PVC | 150 | 14.12 | 0.01 |
| P-141 | 150.00 | PVC | 150 | 8.14 | 0.01 |
| P-221 | 100.00 | PVC | 150 | 0.80 | 0.02 |
| P-49 | 80.00 | PVC | 150 | 14.89 | 0.03 |
| P-179 | 250.00 | PVC | 150 | 10.25 | 0.03 |
| P-223 | 100.00 | PVC | 150 | 0.17 | 0.04 |
| P-30 | 400.00 | DCI | 130 | 14.59 | 0.05 |
| P-161 | 100.00 | PVC | 150 | -0.27 | 0.06 |
| P-186 | 100.00 | HDPE | 120 | 12.87 | 0.06 |
| P-158 | 100.00 | PVC | 150 | 5.12 | 0.06 |
| P-146 | 150.00 | HDPE | 120 | 10.45 | 0.07 |
| P-319 | 150.00 | HDPE | 120 | 1.21 | 0.07 |
| P-26 | 100.00 | HDPE | 120 | 12.32 | 0.09 |

Regarding to Table 4.6, the above 36 pipes in the system has a velocity less than the minimum limits, of minimum velocities which is 0.1-0.3 m/s. Minimum velocities should be avoided from the system in order to avoid stagnation and water quality problems. To resolve this problem, maintaining the limits of minimum pressure. Actually zero (0.00 m/s) velocities are expected in the loop kind of water distribution system.

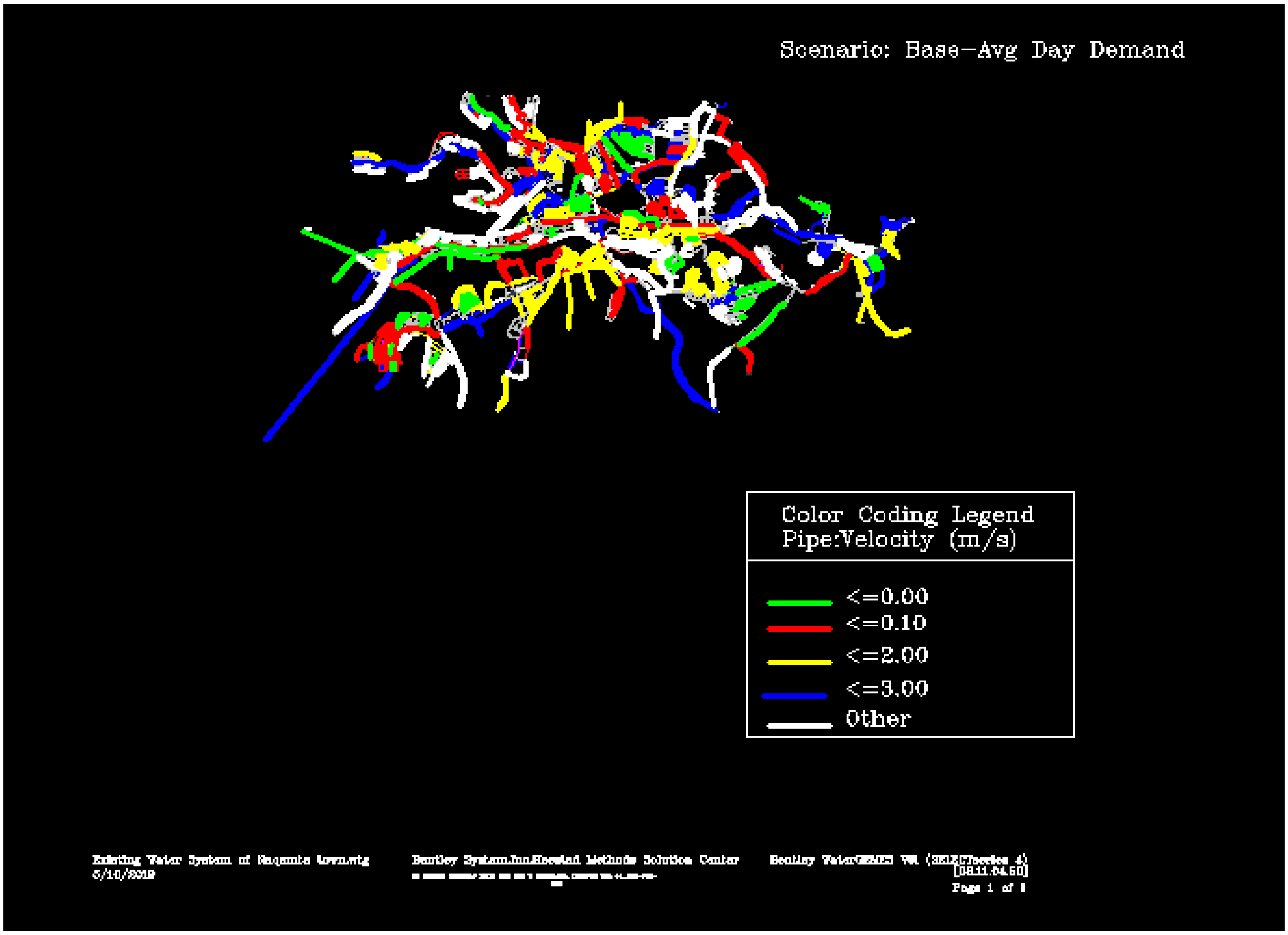


Figure 4.5: Velocity map of links for average day demand

Table 4.7: Links with high velocity

| Label | Diameter (mm) | Material | Hazen-Williams-C | Flow (L/S) | Velocity (m/s) |
|---|---|---|---|---|---|
| P-296 | 80.00 | HDPE | 120 | 2.50 | 5.21 |
| P-236 | 250.00 | PVC | 150 | 1.80 | 6.09 |
| P-325 | 150.00 | HDPE | 120 | 5.32 | 7.54 |
| P-127 | 100.00 | PVC | 150 | 14.89 | 8.02 |

Table 4.8: Existing pipes need to re-size

| Label | Length (scaled) (m) | Diameter (mm) | Revised Diameter (mm) | Material | Hazen-Williams-C | Flow (l/s) | Velocity (m/s) |
|---|---|---|---|---|---|---|---|
| P-12 | 49.65 | 100 | 150 | PVC | 120 | 15.12 | 397 |
| P-49 | 106.89 | 80 | 120 | PVC | 100 | 14.89 | 0.03 |
| P-52 | 80.5 | 80 | 120 | PVC | 110 | -2.94 | 0.67 |
| P-35 | 92.56 | 400 | 450 | DCI | 100 | 14.85 | 0.69 |
| P-84 | 75.12 | 100 | 150 | HDPE | 130 | 12.56 | 0.65 |
| P-61 | 45.65 | 100 | 150 | PVC | 100 | 14.25 | 0.6 |
| P-113 | 100.35 | 150 | 200 | HDPE | 120 | 21.5 | 1.31 |
| P-141 | 50.14 | 150 | 200 | PVC | 130 | 8.14 | 0.01 |
| P-226 | 102.56 | 100 | 150 | PVC | 110 | 1.72 | 3.01 |
| P-186 | 61.21 | 100 | 130 | HDPE | 100 | 12.87 | 0.06 |
| P-244 | 25.65 | 80 | 130 | HDPE | 120 | 1.58 | 3.56 |
| P-89 | 98.65 | 400 | 450 | DCI | 100 | 10.12 | 0.75 |
| P-303 | 89.26 | 200 | 250 | PVC | 150 | 6.72 | 0.37 |
| P-283 | 75.29 | 200 | 250 | PVC | 120 | 5.45 | 0.00 |
| P-318 | 56.15 | 150 | 200 | HDPE | 100 | 1.91 | 0.11 |
| P-144 | 80.65 | 150 | 200 | PVC | 120 | -0.15 | 0.30 |
| P-36 | 65.89 | 150 | 200 | HDPE | 110 | 0.07 | 0.63 |
| P-167 | 75.45 | 200 | 250 | PVC | 150 | 15.88 | 0.94 |

### 4.2.5 Hydraulic calibration and validation

As shown in Figure 4.6 and 4.7; during the comparison of measured pressure value with the simulated one, gaps were recorded up to 14m head and it was out of the pressure standard and limitations suggested by Tomas, *et al*., (2003) and Benyam, (2016). Therefore, the computed pressure for both upper and lower zone, value were calibrated until the result was approach to the observed pressure value.

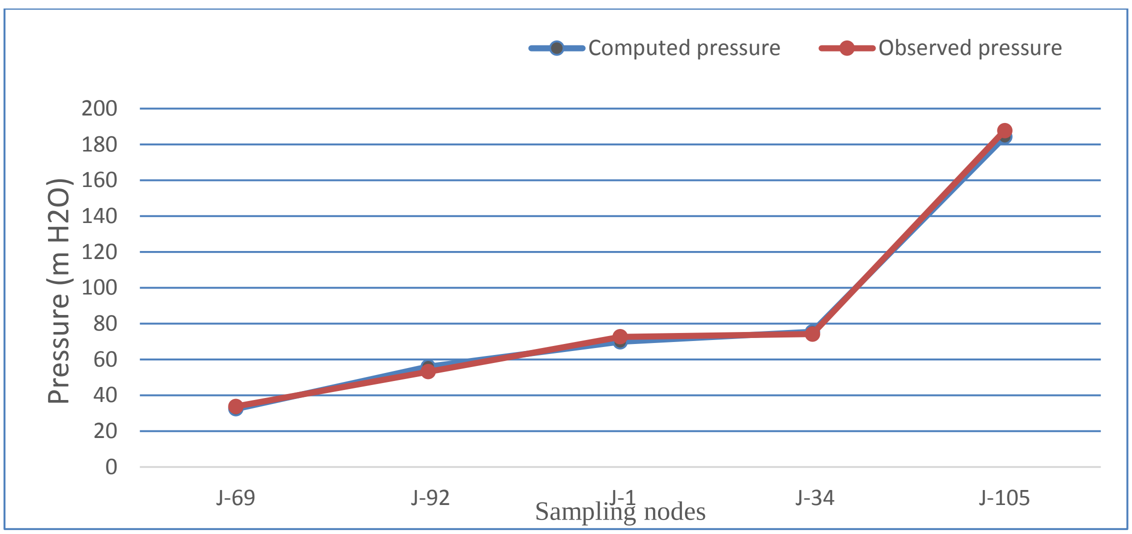


Figure 4.6: Graphical representation of computed and observed pressure value (upper zone) for peak hour demand

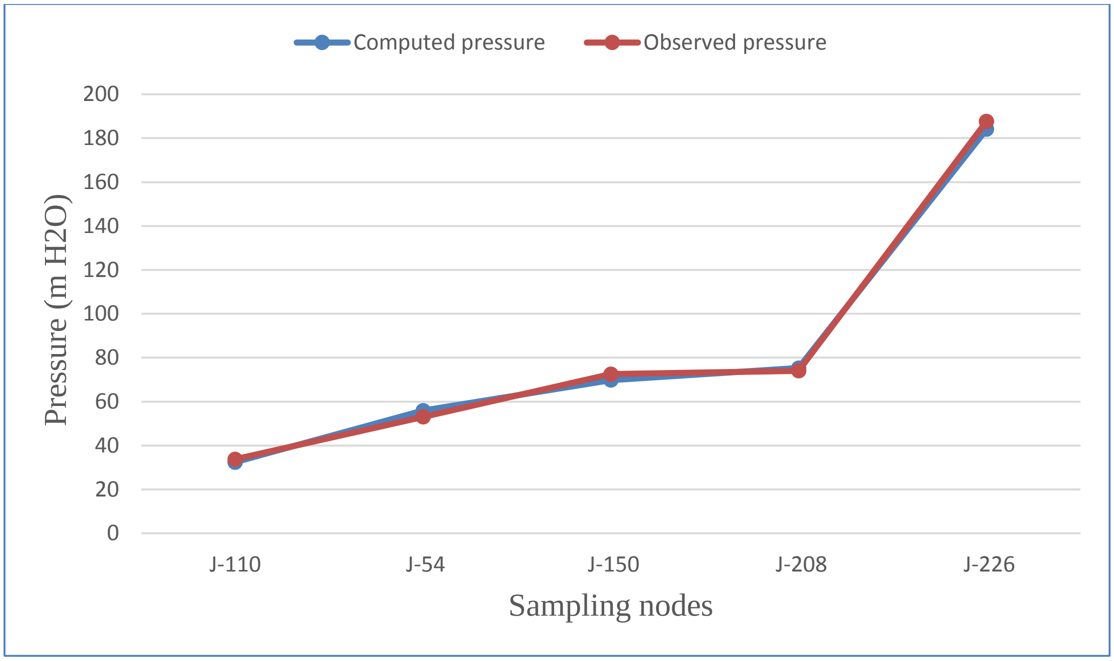


Figure 4.7: Graphical representation of the computed and observed pressure value (lower zone) for peak hour demand

While, as per discussion with the water utility manager, in Naqamte the maximum hour water demand is happen during morning and evening time, when most people use water for bathing, washing and cooking purpose so that incase of higher and lower zone the computed pressure and observed pressure are almost close to each other.

#### 4.2.5.1 Model validation

The model validation work was taken manually using the correlation coefficient equation ($R^2$) method and it were described and represent graphically in figures below. As shown in Figure 4.7 and 4.8; it explains the results of correlation value ($R^2$) for both high and low zone was represent as 99.99% and 99.97%, respectively. Thereby, the calibrated pressure value was validated within the recommended standard.

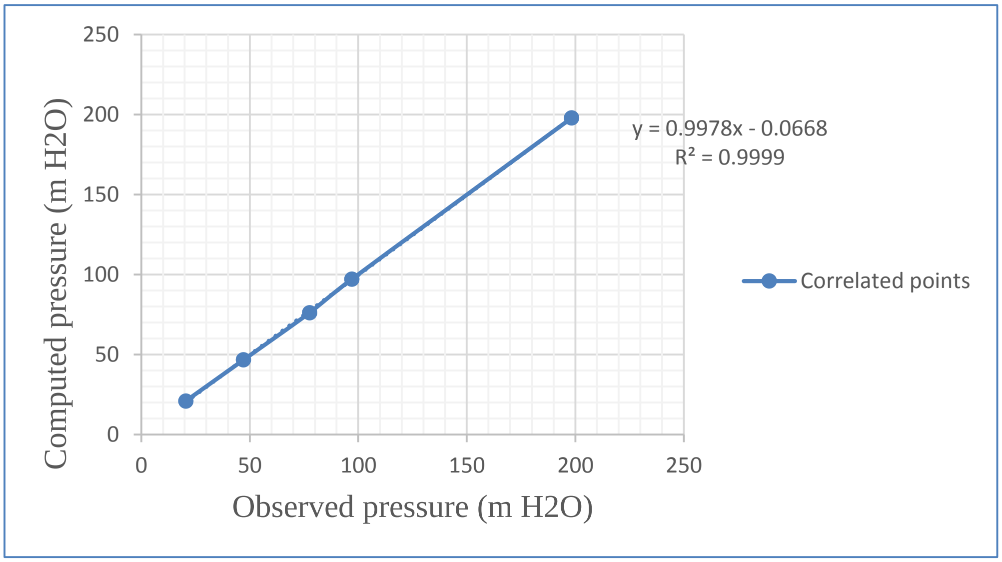


Figure 4.8: Correlated plot during pressure calibration (upper zone) for peak hour demand

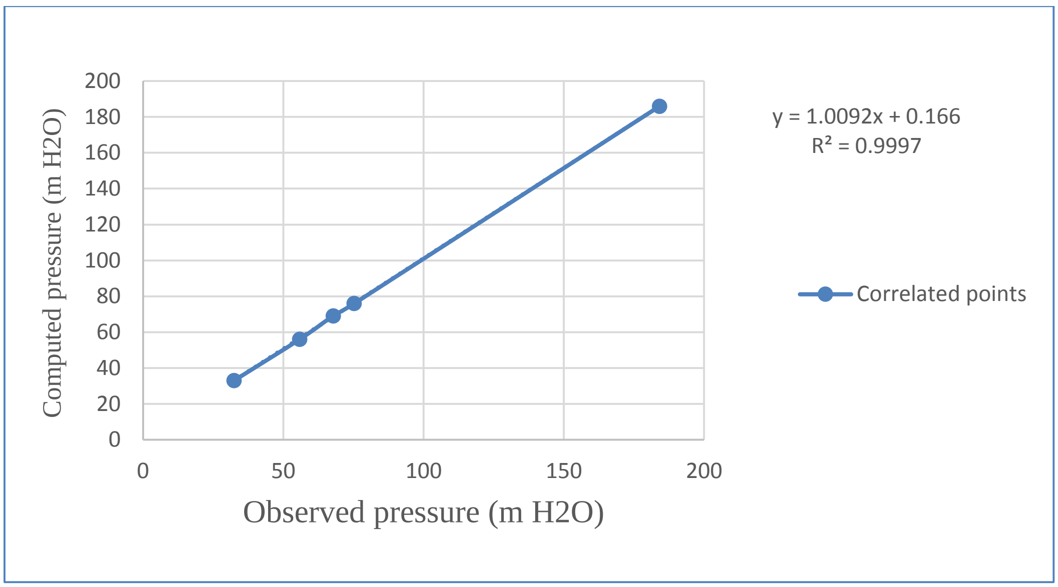


Figure 4.9: Correlated plot during pressure calibration (lower zone) for peak hour demand

## 4.3 Performance of water treatment plant

### 4.3.1 Major unit processes of capability

**A) Flocculation**

As per the design report document of DH Consultant, the total volume of flocculator for eight unit was 720 $m^3$ and the detention time of the unit was found to be 30 minutes. This time was found with in the maximum recommended design range of 20-30 minutes. Thus, flocculation time not results flocs to settle and form scum on the walls and bottoms of the flocculators. The mixing energy (velocity gradient) from the design report was 86.1 $s^{-1}$. It was exist within the recommended design range of 45-90 $s^{-1}$. The head loss of the entire unit was 0.098m, which was less than 0.35-0.5m design range. Thus, partial of the design parameters were within the recommended design ranges. This indicates that there was sufficient mixing and dispersion of coagulant chemicals with the raw water. By using the equation (3.9), the flocculation basin capability was found to be 34,560 $m^3$/d. This, shows that the capacity of flocculation was greater than the current maximum water demand of the town (34,560 $m^3$/d > 12,345.36 $m^3$/d). Therefore, Flocculation chamber exist in a good performance. But the result obtained from Watpro 4.0 has been tabulated under Annexes-P.

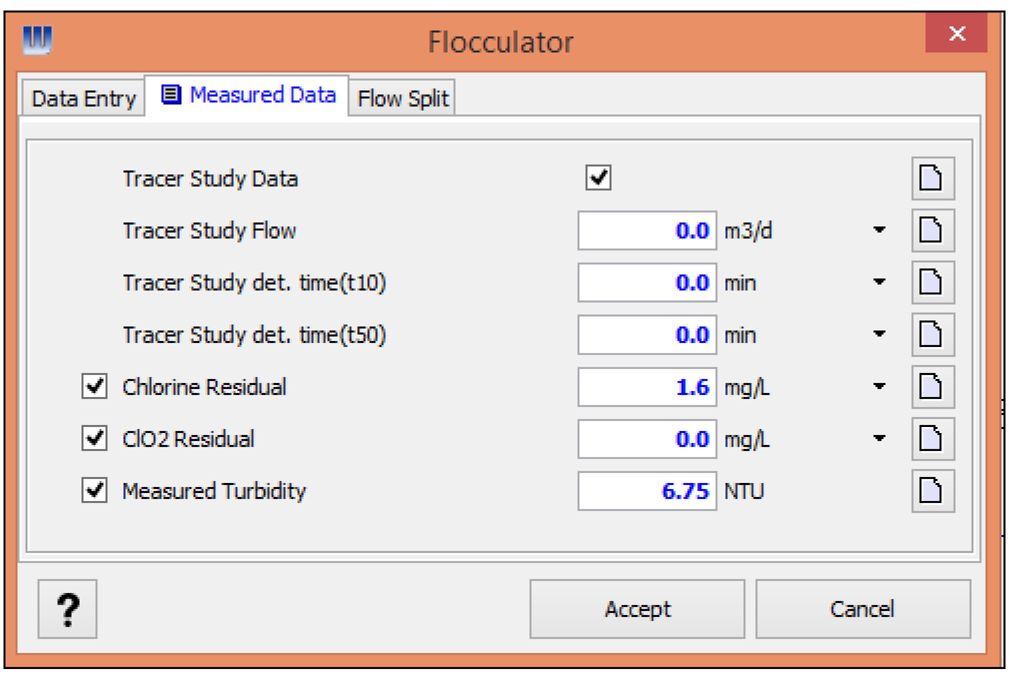


Figure 4.10: Data entry window of flocculator generated by Watpro 4.0

### B) Sedimentation

The two rectangular sedimentation basins have total surface area of 120 $m^2$. The detention time (from the design report) was 4 hours. This detention time was much higher than the design value 3 hours. This indicated the flocculated water spent more time than the required design and the plant was operated at around half of the design flow to the sedimentation basins. From the equation (3.10), sedimentation capability was found to be 3,000 $m^3/d$. This shows that the sedimentation basin performs less than that of the maximum day demand of the town (12,345.36 $m^3/d$). Operators reported routine removal of sludge from sedimentation basins was not being practiced. The sludge was being removed once in three months' time. The sludge deposit in the settling basin was almost half of the total depth. This indicated that too much floc was being accumulated at the bottom of the basin for longer time and become septic causing the sludge to bulk. This could result short circuiting that limits sedimentation performance. But the result obtained from Watpro 4.0 simulator was tabulated under Annexes-Q. Therefore, proper adjustment of hydraulic loading and scheduling of the sludge removal cycle is essential.

### C) Filtration

Single sand media was used in the filtration unit. The filtration rate (from the design report of DH Consultant) was averaged 3.5 m/h this shows that the filters were operated at less than the recommended design loading rate 5-15 m/h range. The lower filter loading rate decreased the potential of filter performance.

This means the filters could be operated at higher loading rates and they can produce more filtered water than the present quantity. From the equation (3.11), the filtration capability was 4,354.56 $m^3/d$. Hence, in case of cope up with the maximum water demand of the town filter basin was not perform in a good condition. But the result obtained from Watpro simulator has been tabulated under Annexes-R. Therefore, the proper adjustment of the filter loading rate and the capability of filtration is the most crucial in order to enhance the potential of filter performance and delivers the amount of water demanded by the town population.

**D) Chlorine contact time**

As per the information suggested under section (3.14 b) and using the equation (3.12), the result of chlorine contact time was 4.8 mg-min/l. Thus, the result was less than the required contact time of 6 mg-min/l. So the result shows that the chlorine added was poorly performed because chlorine contact time was less than the standard value i.e. 4.8 < 6 mg-min/l.

This means to inactivate viruses and bacteria using free chlorine, the disinfection treatment required before the first customer must be at least 6 milligrams- minutes per liter (6 mg-min/L) (www.doh.wa.gov/drinkingwater). Therefore, in case of disinfection by chlorine the chlorine contact time was not enough to inactivate pathogens since the contact time achieved was less than that of the contact time required mean that disinfection efficiency is poorly performed. To get the required contact time value of 6 mg-min/l, it is necessary to adjust the free chlorine residual concentration or the chlorine contact time.

**E) Contact tank**

As per the information suggested under section (3.14 e) and by using the equation (3.13), the result of contact tank was 24 mg-min/l. Thus, this value shows that contact tanks were used a contact time of 24 mg-min/l to disinfect drinking water prior to distribution. Therefore, the required contact time for chlorine contact tank requires 24 mg-min/l to meet the disinfection efficiency.

### 4.3.2 Contact time for water system

By using the idea suggested under section (3.15), annexes-D, and equation (3.14), the result of inactivation ratio for water supply system of the town was 0.476. This shows that the value gained (inactivation ratio) was less than the contact time requirement (0.476 < 1) mean that disinfection efficiency of water system exists in poor condition. Accordingly, this value was complies with the Surface Water Treatment Rules (SWTR) i.e. inactivation ratio must be greater than 1 (one) to ensure contact time for water system efficient (U.S EPA, 1991). Therefore, from such findings the water system did not meet the required contact time so that it performs poorly.

### 4.3.3 Existing plant efficiency

According to the idea listed under section (3.16) and equation (3.16), the result for the existing plant efficiency was 69.75%.

This indicates that treatment plant of the town performs its duty at efficiency rate of 69.75%. Since the plant performs poorly, it is inevitable that the health life of the people exposed to a lot of problems. Therefore, the existing treatment plant efficiency of the town is almost not in good performance to ensure the drinking water quality of the town.

### 4.3.4 Treatment requirements

According to the SWTR **,** all community and noncommunist public water systems which use a surface water source or a ground water under the ,direct influence of a surface water must achieve a minimum of 99.9% (3-log) removal and/or inactivation of Giardia cysts, and a minimum of 99.99 percent (4-log) removal and/or inactivation of viruses. But, as the result obtained from the treatment plant simulated by Watpro shows that the result obtained was lower than that of the standard stated above. Thus, result from the Watpro for Giardia reduction and/ inactivation is 22.6% (log-3) and for viruses removal and /inactivation was 75.34% (log-4). Hence, such result complies with the treatment requirements i.e. Surface Water Treatment Rule (SWTR) so that in case of giardia, viruses, and crypto inactivation and/ removal the treatment plant of the town not exist in a good performance. Therefore, for various amount of disinfectants the following are the results tabulated:

Table 4.9: Inactivation

| Disinfectant Dosage (mg/L) | Giardia Reduction (log(10)) | Virus Reduction (log(10) | Crypto Reduction (log(10)) | |
|---|---|---|---|---|
| 6 | 22.5643 | 75.3254 | 2 | |
| 6.09444 | 22.7747 | 75.3254 | 2 | |
| 6.13889 | 22.9882 | 75.3254 | 2 | |
| 7.58333 | 23.183 | 75.3254 | 2 | |
| 9.02778 | 23.4024 | 75.3254 | 2 | |
| 10.4722 | 23.6027 | 75.3254 | 2 | |
| 11.9167 | 23.8055 | 75.3254 | 2 | |
| 13.3611 | 23.9881 | 75.3254 | 2 | |
| 14.8056 | 24.196 | 75.3254 | 2 | |
| 16.25 | 24.3832 | 75.3254 | 2 | |
| | | | | |

Hence, from the above table it is the fact that the amount of disinfectant can affect the reduction and / inactivation of Giardia (log-3) but for the reduction and/ inactivation of viruses (log-4) and for crypto reduction it is almost constant. Hence, it is advised that in order to increase the reduction/ or inactivation of giardia the disinfectant dosage should be enhanced. The following graph (Figure 4.11) shows more details of the above statement;

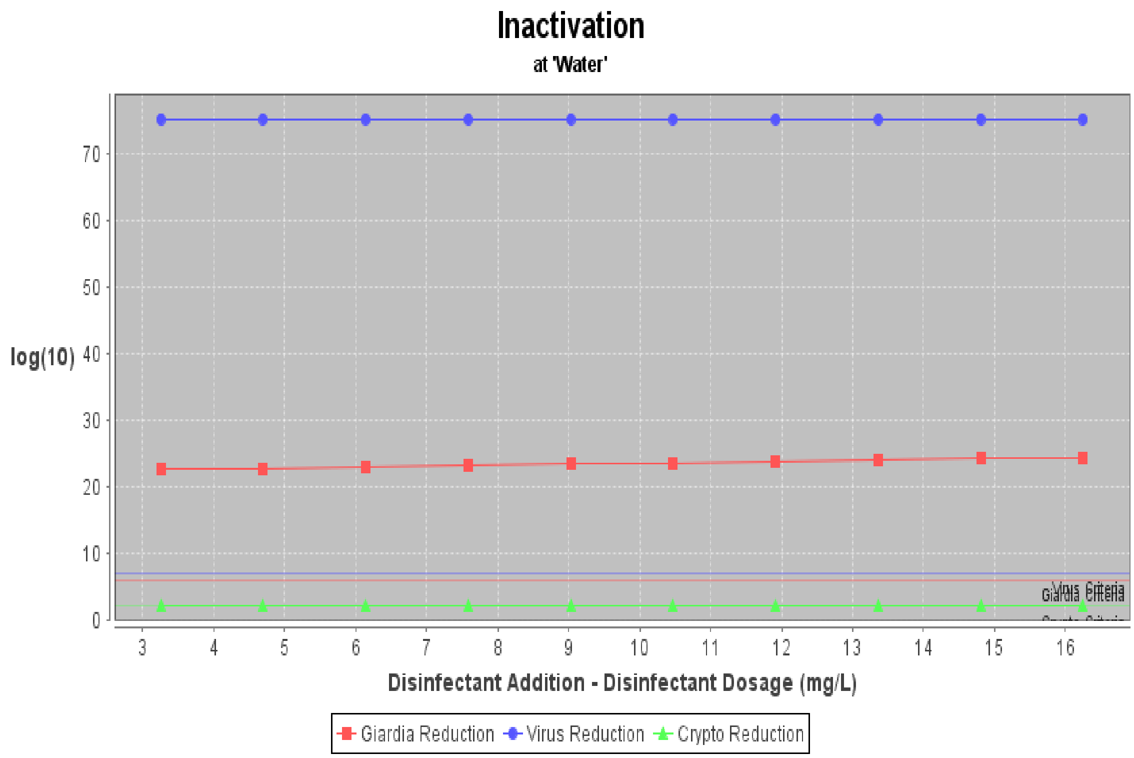


Figure 4.11: Inactivation graph

### 4.3.5 Disinfection By- Product (DBP) formation

While chlorine has been effective for reducing most microbial pathogens to safe levels, it reacts with naturally-occurring matter in the water to form trihalomethanes (THMs) and haloacetic acids (HAAs) as disinfection by-products (DBPs). Therefore, as the result obtained from the WTP simulation the values of those DBPs are tabulated as below (Table 4.10);

Table 4.10: DBPs

| Disinfectant Dosage (mg/L) | TTHMs (ug/L) | HAA5 (ug/L) | Chlorite (ug/L) |
|---|---|---|---|
| 6 | 0.0716945 | 1.45429 | 0 |
| 6.09444 | 0.0820115 | 1.92986 | 0 |
| 6.13889 | 0.0900406 | 2.3829 | 0 |
| 7.58333 | 0.0967059 | 2.82023 | 0 |
| 9.02778 | 0.102097 | 3.24909 | 0 |
| 10.4722 | 0.106796 | 3.66928 | 0 |
| 11.9167 | 0.110798 | 4.08421 | 0 |
| 13.3611 | 0.114425 | 4.4929 | 0 |
| 14.8056 | 0.117346 | 4.90108 | 0 |
| 16.25 | 0.120056 | 5.30447 | 0 |

From the Table 4.10, the result (numerical value) of disinfection by product tabulated indicates that there was the existence of disinfection by product (disease causing pathogens) in treatment plant of the town. Thus, as the disinfectant dosage increases the value of Trihalomethanes and Haloacetic acid increases except that of chlorite. So that their (disinfection by- product) existence may causes a lot of effects on the health life of the population. Therefore, the performance of treatment plant of the town not exist in a good manner to treat drinking water so as to keep the health life of the people. For more precise the above table is illustrated by the following graph (Figure 4.12);

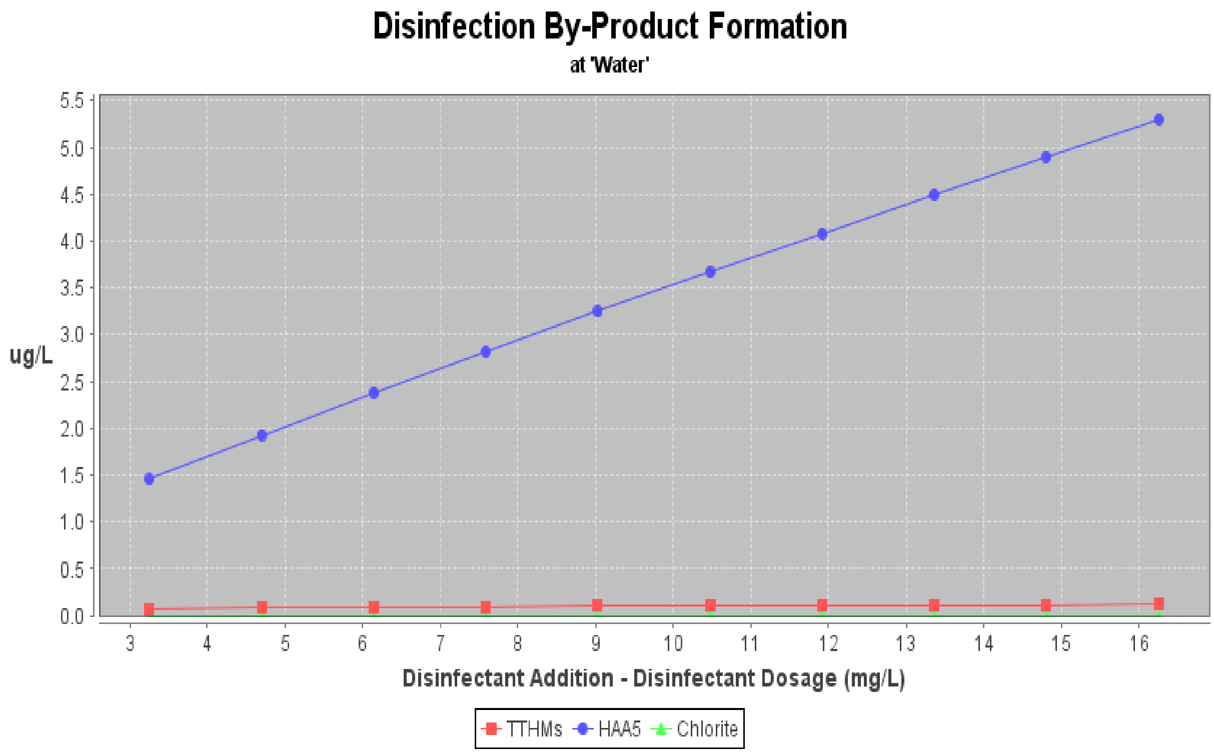


Figure 4.12: DBPs graphs

The ongoing implemented treatment processes including chlorination have been evaluated and simulated using WatPro 4.0 simulator for NWTP. Treatment processes evaluation was based on DBPs generation potential and disinfection effectiveness. Output summary for the treated water is presented in Table 4.11. Health risk factor made DBPs to have highest criteria values. Hence, DBPs generation potential is crucial in the safety of water disinfection assessment mandates.

Table 4.11: Treated water output summary

| Parameters | Criteria | Value | Unit |
|---|---|---|---|
| Effluent chlorine | 4 | 2 | mg/l |
| Effluent chlorine dioxide | 0.8 | 0 | mg/l |
| Effluent chloramines | 1 | 0 | mg/l |
| TTHMs | 100 | 0.09186 | ug/l |
| HAA5s | 100 | 2.49309 | ug/l |
| chlorites | 1 | 0 | Mg/l |
| Total giardia reduction | 6 | 23.0313 | Log(10) |
| Total virus reduction | 7 | 75.3254 | log(10) |
| Total crypto reduction | 2 | 2 | log(10) |
| Turbidity | 0.5 | 1.25 | NTU |

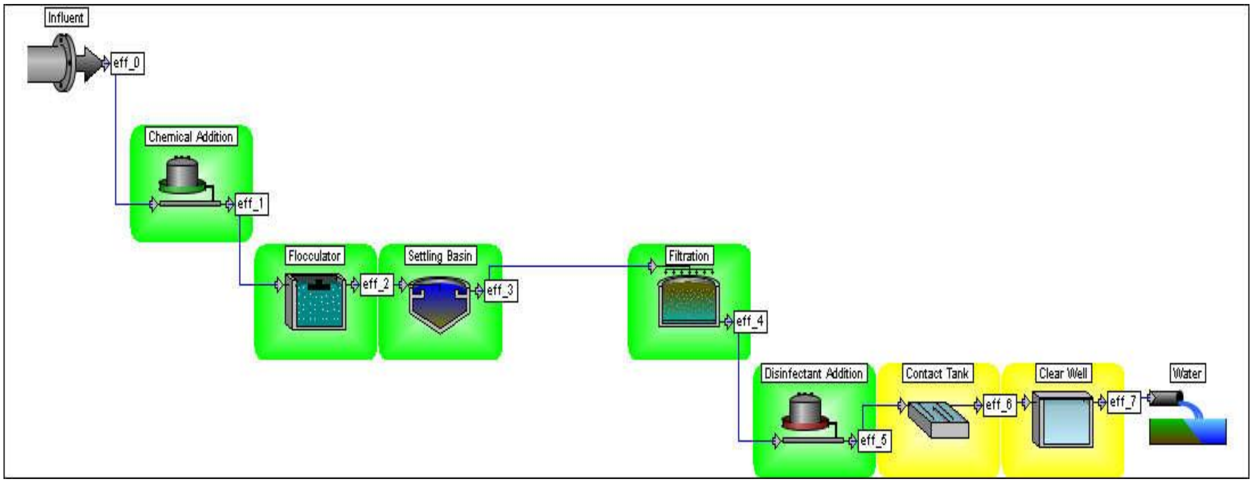


Figure 4.12: Water treatment steps of NWTP using process simulator Watpro 4.0

Effluent treated water quality obtained through the simulation of current chlorination process shows that this disinfection technique may involve serious flaws. Operation conditions like temperature, pH and contact time may have considerable influence on the disinfection success of chlorination respecting pathogens elimination. Regarding to DBPs generation, these factors have low or no significant impacts. The temperature of the treated water was considered 20 $^{o}$C for simulation purposes during all treatment plant steps.

Moreover, the water treatment simulator software WatPro 4.0 has no temperature and time retention control tool specific for chlorination contact tank.

## 4.4 Major factors contributing to water loss in Naqamte town

Water losses are a major problem for water utilities, as they affect environmental and financial sustainability of the town water services. There are several reasons for the high level of water loss in the water distribution networks. As per the discussion made and questions interviewed (Annexes-X ) with the Naqamte water supply service officials and through field observation held, the major sources of water loss experienced throughout Naqamte water distribution system were as a result of;

### 4.4.1 Age and size of pipes

Pipe age and material are important factors that contributes to the burst probability of pipes that as a result causes a lots of water loss. It has been observed that small size and aged pipes were laid in Naqamte town water distribution network. According to the information obtained from Naqamte water supply service office nearly 45% of the pipe were served without any replacement for the last 34 years. Whereby, these pipe materials suffered its quality due to long service time, water carrying capacity and environmental conditions. Therefore, age and pipe size are the main factors for frequent pipe bursting and real losses in the town water distribution network.

Figure 4.13: Pipe bursting (Source: field observation, August, 2019)

### 4.4.2 Metering error (inaccuracy)

As per NWSSO under registration of customer meters is one of the causes of water loss in the town. Like the age of pipes, the age of meters also has an impact to the increase of water loss.

Customer errors in the town happens due to accounting procedure and errors due to under or over registration of the meters. Therefore, as per the water service office, under registration is the main technical problems of customer water meter, and it was found as the main source of apparent loss in Naqamte town water supply system.

### 4.4.3 Illegal connections

According to the water authority of the town, it is such difficult to identify the illegal users of water within Naqamte water distribution network. However, illegal connection is inevitable in the town that contributes to the loss of huge amount of water tariff. Hence, as the information obtained, it is possible to say that illegal connection is one of the major factor that contributes to large volume of water loss in the town.

### 4.4.4 Poor maintenance practices

In many water utilities there is less attention for water loss as a result of their poor maintenance capacities. In Naqamte water service it was observed that; there are no enough budget, proper weak supervision, instrument, accessories, carelessness of the technicians and strong policies for suitable leakage management. However, these have a considerable impact for physical losses in the town water distribution system so that it needs a hot concern to handle the problem.

## 4.5 Leakage management practice

The primary consequence of leaks in distribution system is financial. Reduction in water loss enable water utilities to use existing facilities efficiently, alleviate shortage of water supply, improving the supply capacity to customers and extends the service life of the existing water supply components that as a result to meet the present as well as the future needs of the customers without construction of many new water facilities. As per field observation and information gathered from the officials there is no good leakage management trends has been taken yet.

Figure 4.14: Leakage (Source: field observation, August, 2019)

# CHAPTER FIVE

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

The primary aim of this research was to evaluate the performance of water treatment plant and distribution network of Naqamte town water supply system in Oromiya region of Ethiopia.

The existing water distribution network of Naqamte town was established for an estimated population of 80,160. However, as compared with the current population figure of 137,171, it was served beyond the design life and low coverage in the town. Hence, this emerges the scarcity of drinking water in the town.

Under different demand categories, the current average per capital water consumption of Naqamte town was found as 75 l/c/d. Besides comparing the maximum water demand of the town (12,345.36 $m^3$/day), in contrast the size of existing infrastructural components such as clear water reservoir, pumping station (raw water) and distribution pipes were found small in capacities, and leads to supplying water intermittently. Thereby, it was observed that water pressure in the distribution network were not performing within the proposed maximum and minimum design criteria set by FDRE, MoWIE. Accordingly, the water distribution network were faced a frequent pipe bursts, clogging of some components that leads to destruction, and failures during low demand time and exposed to large volume of water loss especially in high pressure zone areas, while during high demand time mostly residences found in dense population and higher level of the town were not received and/served continuous water from the system.

The water supply coverage of the town was very low 46.16%. Although there is overall shortage of water in the town, predominantly the existing amount of water is fairly distributed among the different localities intermittently. Accordingly, there was complain from the customer because their demand was not matched enough to fulfill their satisfaction since distribution system is intermittent.

Especially, those residences that water supply could not cover their area were in a difficult condition due to lacking the treated water for their domestic need. Hence, this may expose them to various problem like disease and etc. There is very high water loss in the distribution network, about 40% produced water has been recorded wastage due to leakage in the system.

The intermittent supply affects the hydraulic performance of the network and exposes it to high values of pressure and velocities; which results adverse effect on the readings of the customer water meters due to the pushed and sucked air in the network.

The high water loss indicates that the network being serving beyond its design life. Thus, this water loss and leakage has a great impact on the economy of the town. Field observation and discussion held with the NWSSO confirms that there is physical losses and contribute considerable volume of water losses in the distribution system. While, apparent losses are more significant and the major sources of water losses in Naqamte town. Therefore, aging and size of pipe material, meter error (under registration), illegal connections, systematic data handling errors and poor maintenance practices were found as the major factors of water losses in Naqamte town water distribution networks. No good leakage management trends, attention towards water loss management, lack of skilled man power (professionals), carelessness of the workers towards maintenance were the major problems found in Naqamte town water utility.

The current capacities of raw water pumps delivers the water to the treatment plant was 2851.2 $m^3$/d. In contrarily the current maximum water demand of the town was 12,345.36 $m^3$/d. This shows that the current raw water pump capacity did not satisfy the required peak daily water demand of the town.

The major capability of unit process of the treatment plant were found. However, except that of flocculator (34,560 m3/d > 12,345.36 m3/d) their capacity is less than the current maximum day demand of the town. So that except flocculator basin, these major unit were found not in a good condition in order to cope up with the current maximum day demand of the town because their capability is less than the current maximum day demand.

Referring to (Annexes-L), the result obtained from the Watpro 4.0 simulation shows, despite that of disinfectant the unit processes of treatment plant has a great role (performance) in removing impurities from water.

The contact time of water system of the town was found that it’s less than that of inactivation ratio i.e. 0.467 < 1. Thus, this indicates that less effective measurements of disinfection process. The treatment plant performs its duty at a rate of 69.75%, this indicates that the existing treatment plant efficiency of the town is almost not in a good performance to ensure the drinking water quality of the town.

The disinfection by-products were formed in water distribution system since the chlorine is used in treatment plant as disinfectant. Hence, 0.071 ug/l of TTHMs and 1.454 ug/l of HAA5 were exist in water treatment plant of the town. Moreover, 22.56% of giardia, 75.32% of viruses, and 2% of crypto has been inactivated and/reduced. But, inactivation and / removal of giardia, crypto, and viruses computed were less than that of the SWTR standards.

In general, it was summarized that the current water distribution network and treatment plant of Naqamte town was in poor performance and were not conducted adequate water to the various demand categories of the town.

## 5.2 Recommendations

According to this study, the following several items that needs immediate action were mentioned to Naqamte town existing water supply and treatment plant:

Almost some water distribution network components need to be replaced, especially pipe rehabilitation decision should be taken. For the case of Naqamte, by considering that most of existing pipe is still an asset for the utility, in order to reduce water loss through pipe bursting the most advisable and recommended is installation of a parallel main line with larger diameter than replacement of the old line. While, cleaning and removing deposits from the old pipeline walls should be also advised to improve flow through the pipeline and restoring lost carrying capacity in the mains. Additionally, illegal connection, and meter error problem are the other challenges of the water utility. So that, the water authority should be provides customer awareness programs and should be encouraged to report illegal connections, and regulations should be in place to penalize the water thieves.

The water utility should respond immediately to maintenance requests of customers in order to avoid complaints from customers and need to have plan and regular discussions with the customers and should conduct a regular survey to know customer's satisfaction level and the service deficiencies and should make improvements on its service to increase the customer's satisfaction.

The existing demand in the town is much greater than daily water production of the system, so it is important to revise the design and rehabilitate the water distribution system by improving the size of reservoirs capacity and replacing the new raw water pumps with the required hydraulic performance and checking out performance of the other components (maintaining where needed) of the system deliberately, so as to escape from the sudden damage.

In order to control and minimize risks related with variation of pressure, water hammer and back water flow; it was advised installing the necessary valves like pressure reducing valve i.e. in case of reducing pressure the system should have such valve and accessories in the water distribution system and in order to reduce negative pressure, it is better increasing the flow to avoid water stagnation.

It was advised that to minimize or avoid losses of water in distribution network of the town, regular supervision of the network components, and giving responses where needed (especially, pipe bursting), replacing the old components with the new one, is the most way of reducing water losses in the system.

The water utility should prepare the leakage management trends (strategies) for the sake of proper functioning of water distribution components. Thus, leakage through some components can be reduced by such trends.

The water authority of the town should consider the water demand for construction activities conducted and should work on the water harvesting strategies at house hold level. Implementing water conservation strategies such as: Water recycling strategies- Using backwash water for different purpose, such as toilet flushing, gardening, etc rather using clean potable water.

The source (Maqa dam) of water distribution system of the town is being affected by the exotic weeding species so called Emboch so that it is necessary to take immediate action in order to safe the source from drying and to deliver enough raw water to treatment plant.

The water system of the town could not met the contact time requirements because the inactivation ratio is less than one so that it is advised to revise the design and increase the peak hour flow of the system. To control the formation of halogenated by-products (compounds formed by the reaction of a disinfectant, such as chlorine with organic material in the water supply) the following three strategies should be accomplished; i) Remove the by-products after they are formed, which can be difficult and costly. ii) Use alternative disinfectants (like chlorine dioxide) that do not produce undesirable by-products, which is often the most cost-effective strategies. iii) Reduce the concentration of organics in the water before chlorination to minimize the formation of by-products. Additionally, the water authority of the town should be aware of taking in to account the reduction and/inactivation of giardia and viruses in order to make the water system free of pathogens.

In general, the Naqamte water supply authority should investigate and compile all the necessary information or data with regarding to the water system of the town that helps the future expansion of the water supply system of the town and it’s highly advisable that developing a geo database for the whole system is an essential action for the existing system.

Because, Geographic Information System is capable enough to build a reasonable management planning and rehabilitation plans for urban water distribution networks. Hence, it is more advisable that as the system hydraulic operation is to be integrated with Geographical Information System application.

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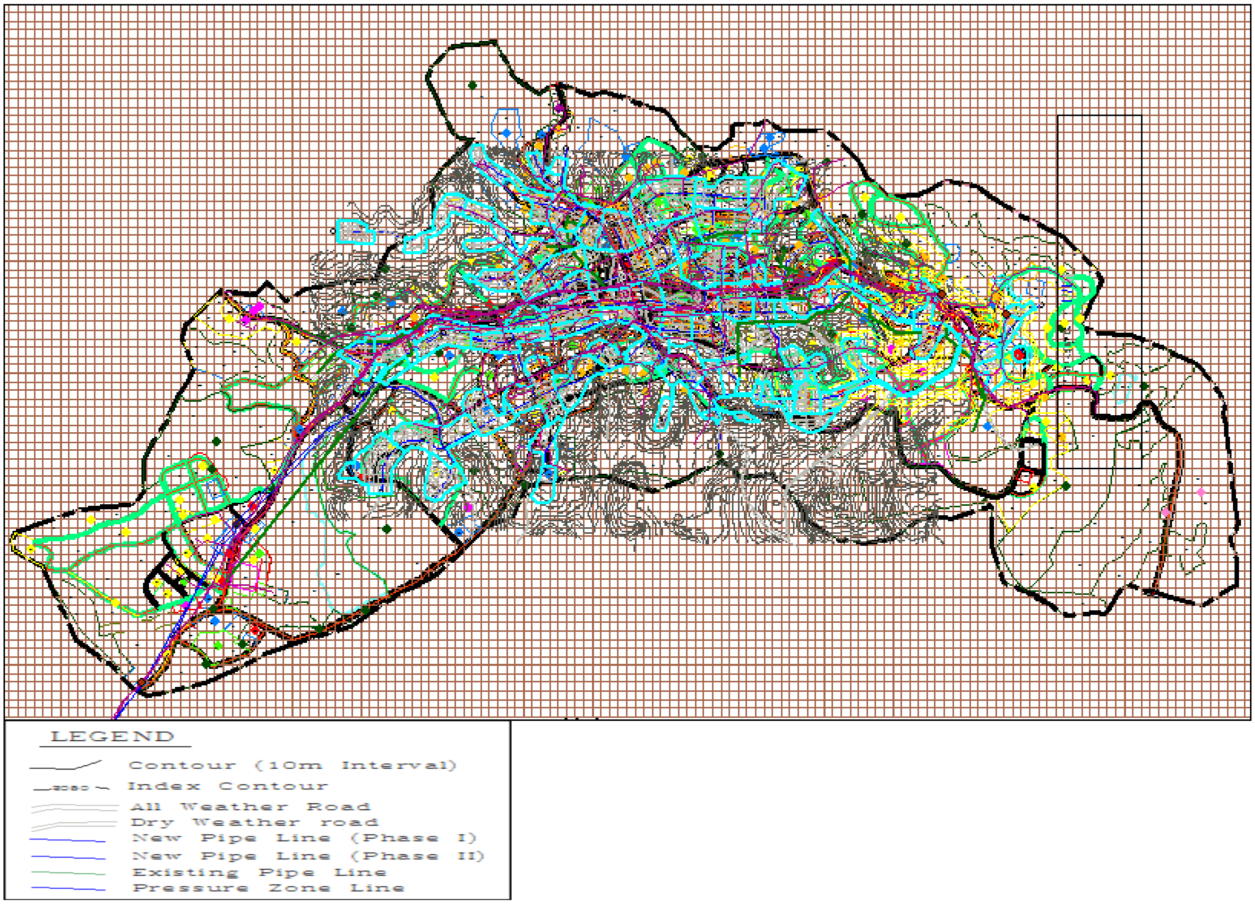
# ANNEXES

**Annexes- A:** Map shown the overlapped distribution pipeline on contour map of the town



**Annexes- B:** CT values for 3-log inactivation of giardia cysts by free chlorine (Source: EPA, 2011)

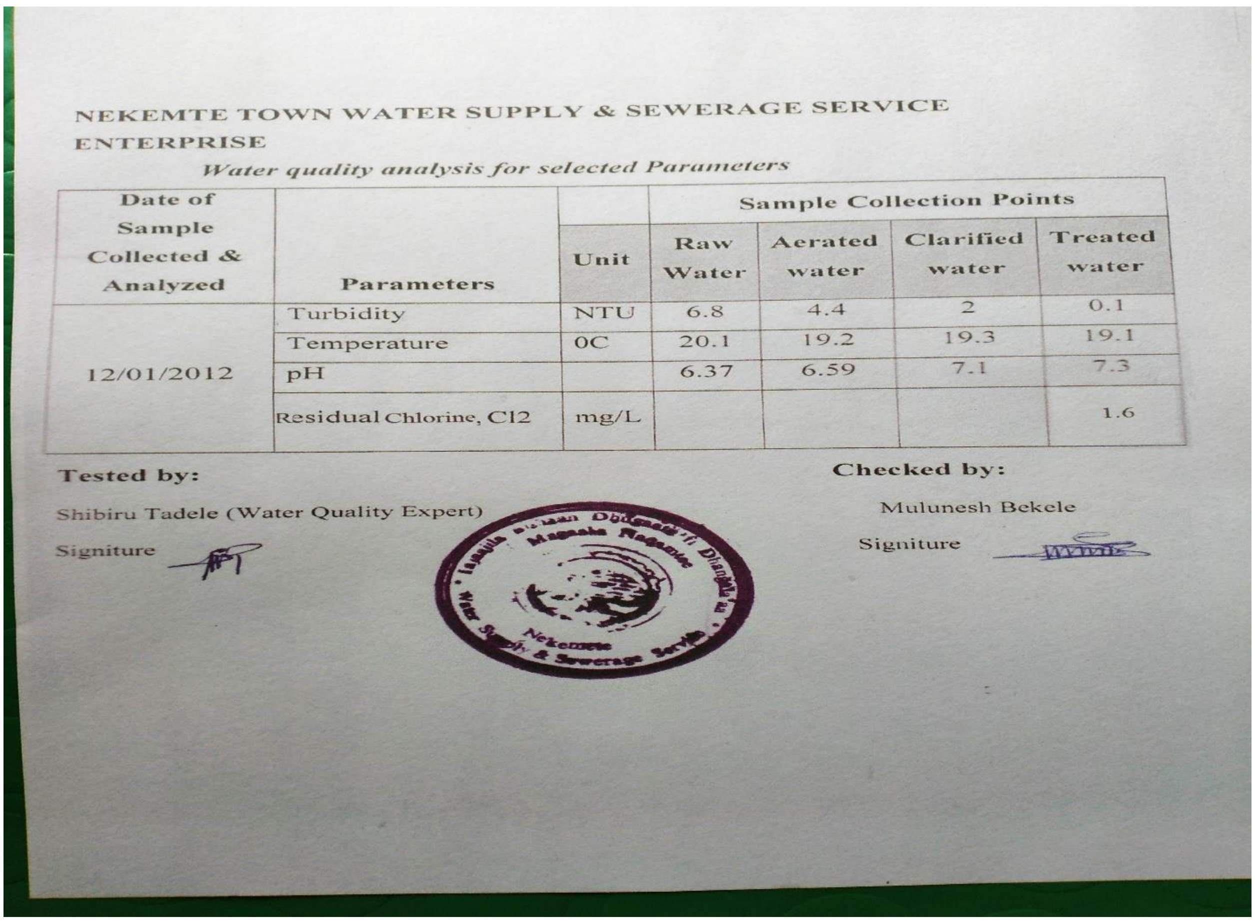
| Chlorine Concentration (mg/L) | Temperature <=0.5°C | | | | | | | Temperature =5°C | | | | | | | Temperature = 10°C | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | | | | | | | pH | | | | | | | pH | | | | | | |
| | <=6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 | <=6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 | <=6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 |
| <=0.4 | 137 | 163 | 195 | 237 | 277 | 329 | 390 | 97 | 117 | 139 | 166 | 198 | 236 | 279 | 73 | 88 | 104 | 125 | 149 | 177 | 209 |
| 0.6 | 141 | 168 | 200 | 239 | 286 | 342 | 407 | 100 | 120 | 143 | 171 | 204 | 244 | 291 | 75 | 90 | 107 | 128 | 153 | 183 | 218 |
| 0.8 | 145 | 172 | 205 | 246 | 295 | 354 | 422 | 103 | 122 | 146 | 175 | 210 | 252 | 301 | 78 | 92 | 110 | 131 | 158 | 189 | 226 |
| 1.0 | 148 | 176 | 210 | 253 | 304 | 365 | 437 | 105 | 125 | 149 | 179 | 216 | 260 | 312 | 79 | 94 | 112 | 134 | 162 | 195 | 234 |
| 1.2 | 152 | 180 | 215 | 259 | 313 | 376 | 451 | 107 | 127 | 152 | 183 | 221 | 267 | 320 | 80 | 95 | 114 | 137 | 166 | 200 | 240 |
| 1.4 | 155 | 184 | 221 | 266 | 321 | 387 | 464 | 109 | 130 | 155 | 187 | 227 | 274 | 329 | 82 | 98 | 116 | 140 | 170 | 206 | 247 |
| 1.6 | 157 | 189 | 226 | 273 | 329 | 397 | 477 | 111 | 132 | 158 | 192 | 232 | 281 | 337 | 83 | 99 | 119 | 144 | 174 | 211 | 253 |
| 1.8 | 162 | 193 | 231 | 279 | 338 | 407 | 489 | 114 | 135 | 162 | 196 | 238 | 287 | 345 | 86 | 101 | 122 | 147 | 179 | 215 | 259 |
| 2.0 | 165 | 197 | 236 | 286 | 346 | 417 | 500 | 116 | 138 | 165 | 200 | 243 | 294 | 353 | 87 | 104 | 124 | 150 | 182 | 221 | 265 |
| 2.2 | 169 | 201 | 242 | 297 | 353 | 426 | 511 | 118 | 140 | 169 | 204 | 248 | 300 | 361 | 89 | 105 | 127 | 153 | 186 | 225 | 271 |
| 2.4 | 172 | 205 | 247 | 298 | 361 | 435 | 522 | 120 | 143 | 172 | 209 | 253 | 306 | 368 | 90 | 107 | 129 | 157 | 190 | 230 | 276 |
| 2.6 | 175 | 209 | 252 | 304 | 368 | 444 | 533 | 122 | 146 | 175 | 213 | 258 | 312 | 375 | 92 | 110 | 131 | 160 | 194 | 234 | 281 |
| 2.8 | 178 | 213 | 257 | 310 | 375 | 452 | 543 | 124 | 148 | 178 | 217 | 263 | 318 | 382 | 93 | 111 | 134 | 163 | 197 | 239 | 287 |
| 3.0 | 181 | 217 | 261 | 316 | 382 | 460 | 552 | 126 | 151 | 182 | 221 | 268 | 324 | 389 | 95 | 113 | 137 | 166 | 201 | 243 | 292 |

| Chlorine Concentration (mg/L) | Temperature = 15°C | | | | | | | Temperature = 20°C | | | | | | | Temperature = 25°C | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | | | | | | | pH | | | | | | | pH | | | | | | |
| | <=6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 | <=6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 | <=6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 |
| <=0.4 | 49 | 59 | 70 | 83 | 99 | 118 | 140 | 36 | 44 | 52 | 62 | 74 | 89 | 105 | 24 | 29 | 35 | 42 | 50 | 59 | 70 |
| 0.6 | 50 | 60 | 72 | 86 | 102 | 122 | 146 | 38 | 45 | 54 | 64 | 77 | 92 | 109 | 25 | 30 | 36 | 43 | 51 | 61 | 73 |
| 0.8 | 52 | 61 | 73 | 88 | 105 | 126 | 151 | 39 | 46 | 55 | 66 | 79 | 95 | 113 | 26 | 31 | 37 | 44 | 53 | 63 | 75 |
| 1.0 | 53 | 63 | 75 | 90 | 108 | 130 | 156 | 39 | 47 | 56 | 67 | 81 | 98 | 117 | 26 | 31 | 37 | 45 | 54 | 65 | 78 |
| 1.2 | 54 | 64 | 76 | 92 | 111 | 134 | 160 | 40 | 48 | 57 | 69 | 83 | 100 | 120 | 27 | 32 | 38 | 46 | 55 | 67 | 80 |
| 1.4 | 55 | 65 | 78 | 94 | 114 | 137 | 165 | 41 | 49 | 58 | 70 | 85 | 103 | 123 | 27 | 33 | 39 | 47 | 57 | 69 | 82 |
| 1.6 | 56 | 66 | 79 | 96 | 116 | 141 | 169 | 42 | 50 | 59 | 72 | 87 | 105 | 126 | 28 | 33 | 40 | 48 | 58 | 70 | 84 |
| 1.8 | 57 | 68 | 81 | 98 | 119 | 144 | 173 | 43 | 51 | 61 | 74 | 89 | 108 | 129 | 29 | 34 | 41 | 49 | 60 | 72 | 86 |
| 2.0 | 58 | 69 | 83 | 100 | 122 | 147 | 177 | 44 | 52 | 62 | 75 | 91 | 110 | 132 | 29 | 35 | 41 | 50 | 61 | 74 | 88 |
| 2.2 | 59 | 70 | 85 | 102 | 124 | 150 | 181 | 44 | 53 | 63 | 77 | 93 | 113 | 135 | 30 | 35 | 42 | 51 | 62 | 75 | 90 |
| 2.4 | 60 | 72 | 86 | 105 | 127 | 153 | 184 | 45 | 54 | 65 | 78 | 95 | 115 | 138 | 30 | 36 | 43 | 52 | 63 | 77 | 92 |
| 2.6 | 61 | 73 | 88 | 107 | 129 | 156 | 188 | 46 | 55 | 66 | 80 | 97 | 117 | 141 | 31 | 37 | 44 | 53 | 65 | 78 | 94 |
| 2.8 | 62 | 74 | 89 | 109 | 132 | 159 | 191 | 47 | 56 | 67 | 81 | 99 | 119 | 143 | 31 | 37 | 45 | 54 | 66 | 80 | 96 |
| 3.0 | 63 | 76 | 91 | 111 | 134 | 162 | 195 | 47 | 57 | 68 | 83 | 101 | 122 | 146 | 32 | 38 | 46 | 55 | 67 | 81 | 97 |

**Annexes- C:** CT Values for 4-log inactivation of Viruses by Free Chlorine

| | Log Inactivation | | | | | |
|---|---|---|---|---|---|---|
| | 2.0 | | 3.0 | | 4.0 | |
| pH | 6-9 | 10 | 6-9 | 10 | 6-9 | 10 |
| Temperature (C) | | | | | | |
| 0.5 | 6 | 45 | 9 | 66 | 12 | 90 |
| 5 | 4 | 30 | 6 | 44 | 8 | 60 |
| 10 | 3 | 22 | 4 | 33 | 6 | 45 |
| 15 | 2 | 15 | 3 | 22 | 4 | 30 |
| 20 | 1 | 11 | 2 | 16 | 3 | 22 |
| 25 | 1 | 7 | 1 | 11 | 2 | 15 |

**Annexes-D:** Water quality analysis for selected parameters



NEKEMTE TOWN WATER SUPPLY & SEWERAGE SERVICE ENTERPRISE

*Water quality analysis for selected Parameters*

| Date of Sample Collected & Analyzed | Parameters | Unit | Sample Collection Points | | | |
|---|---|---|---|---|---|---|
| | | | Raw Water | Aerated water | Clarified water | Treated water |
| 12/01/2012 | Turbidity | NTU | 6.8 | 4.4 | 2 | 0.1 |
| | Temperature | 0C | 20.1 | 19.2 | 19.3 | 19.1 |
| | pH | | 6.37 | 6.59 | 7.1 | 7.3 |
| | Residual Chlorine, Cl2 | mg/L | | | | 1.6 |

**Tested by:**

Shibiru Tadele (Water Quality Expert)

Signiture

**Checked by:**

Mulunesh Bekele

Signiture

**Annexes-E:** Representation of pressure value (upper zone); for peak demand time

| Sampling point | Measured Time (LT) | Computed pressure (m) | Observed pressure (m) | Location | | |
|---|---|---|---|---|---|---|
| | | | | X(m) | Y(m) | Z(m) |
| J-34 | 2:30 | 97.48 | 99.01 | 604,014.61 | 895,736.95 | 1,895.00 |
| J-1 | 2:45 | 65.60 | 64.24 | 604,173.55 | 896,035.09 | 1,900.00 |
| J-69 | 3:25 | 65.11 | 65.20 | 603,125.26 | 896,134.07 | 2,000.00 |
| J-92 | 4:00 | 37.15 | 34.39 | 603,758.49 | 895,361.32 | 1,7000 |
| J-105 | 4:30 | 18.32 | 18.64 | 604,067.83 | 896,121.22 | 1,885.00 |

**Annexes- F:** Representation of pressure value (lower zone); for peak demand time

| Sampling point | Measured Time (LT) | Computed pressure (m) | Observed pressure (m) | Location | | |
|---|---|---|---|---|---|---|
| | | | | X(m) | Y(m) | Z(m) |
| J-54 | 2:00 | 68.14 | 71.72 | 604,132.00 | 895,675.26 | 2,000.00 |
| J-150 | 2:45 | 67.24 | 66.38 | 603,645.78 | 895,689.02 | 1,900.00 |
| J-110 | 3:30 | 58.15 | 59.20 | 604,034.37 | 895,547.70 | 1,900.00 |
| J-226 | 4:10 | 21.14 | 19.75 | 603,854.25 | 896,978.00 | 1,800.00 |
| J-208 | 4:45 | 18.27 | 16.40 | 603,960.25 | 896,870.25 | 1,200.00 |

**Annexes- G:** pump result; calculated water result (kW)

| Time (Hr) | Calculated water power (kw) |
|---|---|
| 0:00:00 | 31.2 |
| 1:00:00 | 31.2 |
| 2:00:00 | 31.2 |
| 3:00:00 | 31.2 |
| 4:00:00 | 0.00 |
| 5:00:00 | 0.00 |
| 6:00:00 | 26.30 |
| 7:00:00 | 13.48 |
| 8:00:00 | 18.50 |
| 9:00:00 | 0.00 |
| 10:00:00 | 0.00 |
| 11:00:00 | 26.14 |
| 12:00:00 | 13.40 |
| 13:00:00 | 18.24 |
| 14:00:00 | 30.60 |
| 15:00:00 | 0.00 |
| 16:00:00 | 0.00 |
| 17:00:00 | 26.20 |
| 18:00:00 | 19.12 |
| 19:00:00 | 0.00 |
| 20:00:00 | 0.00 |
| 21:00:00 | 0.00 |
| 22:00:00 | 25.18 |
| 23:00:00 | 0.00 |
| 24:00:00 | 29.50 |

**WaterGEMS V8i simulation run@8:45, steady state analysis**

**Annexes- H1:** Pipe report result; during average day demand time

| Label | Length (m) | Diameter (mm) | Material | Hazen-Williams C | Discharge (l/s) | Pressure Pipe Headloss (m) | Headloss Gradient (m/km) | Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|
| P-1 | 85.15 | 80 | PVC | 150 | 9.95 | 0.87 | 1.26 | 1.27 |
| P-2 | 45.62 | 100 | PVC | 150 | 12.1 | 0.15 | 3.37 | 0.5 |
| P-3 | 49.56 | 80 | PVC | 150 | 10.25 | 0.03 | 0.67 | 0.18 |
| P-4 | 51.63 | 150 | PVC | 150 | -21.35 | 0.55 | 0.25 | 0.6 |
| P-5 | 59.16 | 80 | HDPE | 120 | -2.35 | 0.23 | 3.87 | 0.47 |
| P-6 | 85.59 | 300 | HDPE | 120 | 11.31 | 0 | 0.63 | 0.65 |
| P-7 | 80.26 | 100 | HDPE | 120 | 10.25 | 0.16 | 3.9 | 0.54 |
| P-8 | 93.52 | 150 | HDPE | 120 | 11.25 | 3.77 | 2.56 | 0.8 |
| P-9 | 45.63 | 300 | PVC | 150 | 14.26 | 1.01 | 2.8 | 1.16 |
| P-10 | 100.85 | 100 | PVC | 150 | 14.12 | 0.8 | 1.62 | 0.01 |
| P-11 | 108.65 | 200 | PNC | 150 | 14.13 | 1.25 | 1.65 | 0.65 |
| P-12 | 49.65 | 100 | PVC | 150 | 15.12 | 0.59 | 4.12 | 3.97 |
| P-13 | 66.52 | 150 | PVC | 150 | 15.12 | 0.12 | 0.63 | 1.53 |
| P-14 | 141.48 | 150 | PVC | 150 | 14.16 | 5.32 | 0.59 | 1.54 |
| P-15 | 51.89 | 300 | PVC | 150 | 10.12 | 0.08 | 1.84 | 1.86 |
| P-16 | 66.36 | 100 | PVC | 150 | 12.78 | 0.5 | 1.45 | 3.32 |
| P-17 | 64.78 | 200 | PVC | 150 | 10.32 | 0.08 | 1.25 | 1.68 |
| P-18 | 83.19 | 250 | PVC | 150 | 10.15 | 0 | 2.89 | 0.86 |
| P-19 | 58.26 | 250 | PVC | 150 | 10.12 | 0 | 2.89 | 0.93 |
| P-20 | 96.25 | 80 | PVC | 150 | 12.98 | 0 | 0.63 | 0.44 |
| P-21 | 30.47 | 250 | PVC | 150 | 5.32 | 0 | 0.54 | 0.63 |
| P-22 | 156.25 | 250 | PVC | 150 | 5.52 | 0.9 | 0.46 | 0.58 |
| P-23 | 85.31 | 230 | HDPE | 120 | -0.43 | 0.06 | 0.89 | 0.88 |
| P-24 | 97.23 | 300 | HDPE | 120 | -0.23 | 0.08 | 0.41 | 0.47 |
| P-25 | 120.89 | 200 | HDPE | 120 | -0.08 | 0.12 | 0.06 | 0.16 |
| P-26 | 80.6 | 100 | HDPE | 120 | 12.32 | 0.11 | 0.68 | 0.09 |
| P-27 | 65.2 | 200 | HDPE | 120 | 13.12 | 0.2 | 0.25 | 0.1 |
| P-28 | 84.15 | 400 | DCI | 130 | 14.15 | 0.05 | 16.25 | 0.69 |
| P-29 | 100.78 | 500 | DCI | 130 | 14.63 | 0.8 | 5.22 | 0.53 |
| P-30 | 68.58 | 400 | DCI | 130 | 14.52 | 0.06 | 0.06 | 0.05 |
| P-31 | 95.63 | 400 | DCI | 130 | 14.56 | 1.33 | 4.45 | 0.48 |
| P-32 | 102.56 | 400 | DCI | 130 | 14.25 | 1.08 | 7.62 | 0.65 |
| P-33 | 100.26 | 500 | DCI | 130 | 14.26 | 1.3 | 2.7 | 0.00 |
| P-34 | 85.41 | 400 | DCI | 130 | 14.19 | 0.06 | 0.73 | 0.18 |
| P-35 | 92.56 | 400 | DCI | 130 | 14.85 | 0.08 | 2.69 | 0.69 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| P-36 | 65.89 | 100 | HDPE | 120 | 12.23 | 0.07 | 2.47 | 0.63 |
| P-37 | 120.65 | 300 | HDPE | 120 | 12.15 | 0.03 | 2.51 | 2.04 |
| P-38 | 150.85 | 300 | HDPE | 120 | 8.12 | 0.5 | 1.63 | 1.84 |
| P-39 | 147.98 | 300 | HDPE | 120 | -0.14 | 0 | 1.23 | 0.28 |
| P-40 | 70.65 | 350 | HDPE | 120 | -0.1 | 0 | 3.29 | 0.21 |
| P-41 | 63.2 | 250 | HDPE | 120 | 9.25 | 0 | 4.18 | 0.23 |
| P-42 | 95.45 | 300 | HDPE | 120 | -2.38 | 0 | 4.12 | 0.00 |
| P-43 | 100.62 | 300 | PVC | 150 | -10.17 | 0 | 4.32 | 2.3 |
| P-44 | 80.41 | 200 | PVC | 150 | -11.57 | 0 | 4.15 | 2.62 |
| P-45 | 56.21 | 100 | PVC | 150 | 2.36 | 0 | 0.56 | 2.42 |
| P-46 | 120.87 | 100 | PVC | 150 | -0.37 | 0.01 | 0.25 | 0.76 |
| P-47 | 56.23 | 100 | PVC | 150 | 14.25 | 0.09 | 0.38 | 1.46 |
| P-48 | 130.95 | 100 | PVC | 150 | 14.56 | 0.04 | 0.12 | 0.95 |
| P-49 | 106.89 | 80 | PVC | 150 | 14.89 | 0.01 | 0.03 | 0.03 |
| P-50 | 140.56 | 80 | PVC | 150 | 10.25 | 0.27 | 0.7 | 0.18 |
| P-51 | 120.63 | 80 | PVC | 150 | 6.25 | 0.5 | 154.91 | 1.65 |
| P-52 | 80.5 | 80 | PVC | 150 | -2.94 | 0 | 8.01 | 0.67 |
| P-53 | 80.65 | 80 | PVC | 150 | -0.32 | 0 | 27.48 | 0.003 |
| P-54 | 80.63 | 200 | PVC | 150 | 4.86 | 0 | 4.18 | 0.32 |
| P-55 | 85.45 | 200 | PVC | 150 | 10.63 | 0 | 4.13 | 0.31 |
| P-56 | 92.51 | 350 | PVC | 150 | 9.25 | 0.8 | 1.49 | 0.89 |
| P-57 | 100.36 | 350 | PVC | 150 | 11.89 | 0.12 | 23.01 | 0.64 |
| P-58 | 150.49 | 350 | PVC | 150 | 12.36 | 0.85 | 2.32 | 0.17 |
| P-59 | 65.12 | 350 | PVC | 150 | 12.87 | 0.45 | 2.59 | 0.68 |
| P-60 | 52.96 | 150 | PVC | 150 | 9.25 | 0.78 | 2.16 | 0.52 |
| P-61 | 45.65 | 100 | PVC | 150 | 14.25 | 0.96 | 2.41 | 0.6 |
| P-62 | 89.52 | 150 | PVC | 150 | 8.45 | 0.56 | 2.59 | 0.88 |
| P-63 | 25.64 | 150 | PVC | 150 | 10.75 | 0 | 2.54 | 0.78 |
| P-64 | 150.56 | 150 | PVC | 150 | 10.26 | 0 | 2.65 | 2.13 |
| P-65 | 60.58 | 200 | PVC | 150 | 10.36 | 0 | 2.17 | 0.33 |
| P-66 | 125.62 | 150 | PVC | 150 | 10.87 | 0.96 | 0.06 | 1.76 |
| P-67 | 80.14 | 150 | PVC | 150 | 10.56 | 0.65 | 0.8 | 0.89 |
| P-68 | 100.89 | 150 | PVC | 150 | 6.91 | 0.37 | 0.1 | 1.56 |
| P-69 | 95.32 | 150 | PVC | 150 | 12.36 | 0.84 | 0.75 | 0.00 |
| P-70 | 120.75 | 150 | PVC | 150 | 12.36 | 0.55 | 0.65 | 0.32 |
| P-71 | 29.47 | 150 | PVC | 150 | 13.2 | 0.85 | 0.54 | 1.29 |
| P-72 | 100.54 | 150 | PVC | 150 | 5.58 | 0.67 | 0.68 | 1.26 |
| P-73 | 80.42 | 150 | PVC | 150 | 10.12 | 0.41 | 0.69 | 0.18 |
| P-74 | 65.98 | 200 | PVC | 150 | 23.4 | 0.7 | 0.21 | 4.25 |
| P-75 | 90.24 | 200 | PVC | 150 | 10.25 | 0.08 | 0.65 | 0.17 |
| P-76 | 100.45 | 200 | PVC | 150 | 10.25 | 0.85 | 2.19 | 0.33 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| P-77 | 80.47 | 200 | PVC | 150 | 8.26 | 0.36 | 10.45 | 0.77 |
| P-78 | 106.12 | 200 | PVC | 150 | -9.04 | 0 | 64.2 | 2.05 |
| P-79 | 90.45 | 200 | PVC | 150 | -18.1 | 0 | 2.56 | 4.1 |
| P-80 | 100.85 | 200 | PVC | 150 | 11.49 | 0 | 1.12 | 2.6 |
| P-81 | 60.48 | 200 | PVC | 150 | 12.36 | 0 | 1.65 | 0.2 |
| P-82 | 90.65 | 200 | PVC | 150 | 12.75 | 0 | 1.26 | 0.59 |
| P-83 | 85.56 | 200 | PVC | 150 | 12.56 | 0 | 0.7 | 0.86 |
| P-84 | 75.12 | 100 | HDPE | 120 | 12.56 | 0 | 0.4 | 0.65 |
| P-85 | 56.35 | 100 | HDPE | 120 | 10.25 | 0 | 0.56 | 0.44 |
| P-86 | 80.25 | 100 | HDPE | 120 | 10.25 | 0 | 0.52 | 0.67 |
| P-87 | 100.65 | 100 | HDPE | 120 | 2.99 | 0 | 0.65 | 0.00 |
| P-88 | 80.45 | 100 | HDPE | 120 | 14.61 | 0 | 0.14 | 3.31 |
| P-89 | 98.65 | 400 | DCI | 130 | 10.12 | 0 | 0.24 | 0.75 |
| P-90 | 65.23 | 400 | DCI | 130 | 15.12 | 0.89 | 0.85 | 1.67 |
| P-91 | 120.64 | 400 | DCI | 130 | 12.1 | 0.47 | 0.96 | 3.44 |
| P-92 | 70.47 | 400 | DCI | 130 | 10.36 | 0.19 | 0.45 | 2.52 |
| P-93 | 56.25 | 400 | DCI | 130 | 15.12 | 0.72 | 0.32 | 1.09 |
| P-94 | 100.47 | 400 | DCI | 130 | 15.45 | 0.49 | 4.21 | 1.9 |
| P-95 | 80.64 | 400 | DCI | 130 | 15.63 | 0.15 | 4.85 | 1.77 |
| P-96 | 120.98 | 400 | DCI | 130 | 12.45 | 0.7 | 3.25 | 0.17 |
| P-97 | 50.46 | 400 | DCI | 130 | 8.15 | 0.24 | 3.21 | 0.52 |
| P-98 | 69.32 | 400 | DCI | 130 | 8.69 | 0.51 | 3.56 | 2.1 |
| P-99 | 85.47 | 250 | PVC | 150 | 8.25 | 0.56 | 3.98 | 0.008 |
| P-100 | 105.85 | 250 | PVC | 150 | 10.45 | 1.54 | 3.85 | 0.45 |
| P-101 | 80.65 | 250 | PVC | 150 | 10.75 | 1.3 | 3.18 | 3.23 |
| P-102 | 120.74 | 250 | PVC | 150 | 10.25 | 0.42 | 3.65 | 1.36 |
| P-103 | 156.89 | 250 | PVC | 150 | 10.63 | 0.19 | 3.45 | 0.55 |
| P-104 | 50.25 | 250 | PVC | 150 | 10.25 | 0.74 | 3.52 | 0.38 |
| P-105 | 80.49 | 250 | PVC | 150 | 12.14 | 0 | 3.95 | 0.63 |
| P-106 | 120.89 | 100 | PVC | 150 | 10.26 | 0 | 3.65 | 0.007 |
| P-107 | 109.75 | 100 | PVC | 150 | 10.36 | 0 | 0.14 | 0.63 |
| P-108 | 130.86 | 100 | PVC | 150 | 10.25 | 0 | 0.52 | 0.85 |
| P-109 | 85.65 | 150 | PVC | 150 | 10.34 | 0 | 0.63 | 0.45 |
| P-110 | 54.21 | 150 | PVC | 150 | 5.93 | 0 | 0.98 | 0.65 |
| P-111 | 100.96 | 150 | PVC | 150 | -10.15 | 0 | 0.85 | 0.33 |
| P-112 | 180.12 | 150 | PVC | 150 | -0.94 | 0 | 0.06 | 0.24 |
| P-113 | 100.35 | 150 | HDPE | 120 | 21.5 | 0 | 0.02 | 1.31 |
| P-114 | 85.21 | 150 | HDPE | 120 | 20.15 | 0 | 0.78 | 1.31 |
| P-115 | 97.25 | 150 | HDPE | 120 | 13.25 | 0 | 0.04 | 1.76 |
| P-116 | 75.48 | 150 | HDPE | 120 | 10.25 | 1.02 | 6.21 | 0.58 |
| P-117 | 85.12 | 150 | HDPE | 120 | 10.63 | 0.09 | 40.53 | 0.004 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| P-118 | 50.65 | 250 | HDPE | 120 | 10.85 | 1.32 | 3.3 | 0.41 |
| P-119 | 56.87 | 250 | HDPE | 120 | 10.45 | 2.02 | 7.76 | 0.65 |
| P-120 | 95.2 | 250 | HDPE | 120 | 10.89 | 0.05 | 158.75 | 1.67 |
| P-121 | 80.12 | 250 | HDPE | 120 | 10.78 | 2.28 | 0.23 | 0.6 |
| P-122 | 100.19 | 100 | HDPE | 120 | 9.75 | 2.8 | 0.63 | 0.58 |
| P-123 | 120.75 | 100 | PVC | 150 | 14.25 | 0.07 | 0.45 | 2.41 |
| P-124 | 47 | 100 | PVC | 150 | 14.25 | 0.14 | 0.35 | 0.4 |
| P-125 | 0.85 | 100 | PVC | 150 | 14.63 | 0.15 | 0.23 | 0.99 |
| P-126 | 180.74 | 100 | PVC | 150 | 14.52 | 0.5 | 0.32 | 0.98 |
| P-127 | 65.25 | 100 | PVC | 150 | 14.89 | 0.85 | 217.3 | 8.02 |
| P-128 | 120.96 | 100 | PVC | 150 | 14.56 | 0.69 | 271.33 | 2.23 |
| P-129 | 85.41 | 100 | PVC | 150 | 14.57 | 0.8 | 158.92 | 1.67 |
| P-130 | 75.65 | 100 | PVC | 150 | 9.56 | 0 | 198.04 | 3.76 |
| P-131 | 100.45 | 100 | PVC | 150 | 9.25 | 0 | 30.18 | 1.36 |
| P-132 | 95.21 | 100 | PVC | 150 | 9.47 | 0 | 153.61 | 3.28 |
| P-133 | 150.98 | 100 | PVC | 150 | 12.25 | 0 | 0.06 | 0.36 |
| P-134 | 100.45 | 250 | PVC | 150 | 10.16 | 0 | 0.02 | 0.54 |
| P-135 | 150.25 | 250 | PVC | 150 | 10.96 | 0 | 0.07 | 0.02 |
| P-136 | 108.45 | 250 | PVC | 150 | 15.21 | 0 | 0.09 | 0.98 |
| P-137 | 85.14 | 250 | PVC | 150 | 15.54 | 0.03 | 0.91 | 0.65 |
| P-138 | 98.24 | 250 | PVC | 150 | 15.75 | 0.01 | 0.58 | 0.98 |
| P-139 | 150.48 | 250 | PVC | 150 | 2.94 | 0.09 | 0.06 | 0.12 |
| P-140 | 80.45 | 250 | PVC | 150 | -0.76 | 0.01 | 0.09 | 1.55 |
| P-141 | 50.14 | 150 | PVC | 150 | 8.14 | 0.05 | 0.01 | 0.01 |
| P-142 | 89.54 | 150 | PVC | 150 | 4.59 | 0.01 | 0.63 | 1.04 |
| P-143 | 102.74 | 150 | PVC | 150 | -0.21 | 0.08 | 0.35 | 0.43 |
| P-144 | 80.65 | 150 | PVC | 150 | -0.15 | 0.04 | 0.46 | 0.3 |
| P-145 | 95.62 | 150 | PVC | 150 | 10.98 | 0.07 | 0.01 | 0.98 |
| P-146 | 65.25 | 150 | HDPE | 120 | 10.45 | 0.15 | 0.02 | 0.07 |
| P-147 | 120.48 | 150 | HDPE | 120 | 5.18 | 0.86 | 0.41 | 0.35 |
| P-148 | 89.21 | 150 | HDPE | 120 | 2.7 | 0.38 | 6.83 | 0.29 |
| P-149 | 85.21 | 150 | HDPE | 120 | 1.56 | 0.59 | 2.38 | 0.78 |
| P-150 | 100.65 | 400 | DCI | 130 | 10.63 | 0.75 | 2.58 | 0.18 |
| P-151 | 106.9 | 400 | DCI | 130 | 15.25 | 0.15 | 24.8 | 1.22 |
| P-152 | 100.47 | 400 | DCI | 130 | 10.14 | 0.48 | 0.03 | 0.03 |
| P-153 | 85.45 | 400 | DCI | 130 | 10.86 | 0.09 | 0.45 | 1.75 |
| P-154 | 56.25 | 400 | DCI | 130 | 5.25 | 0.18 | 0.21 | 0.65 |
| P-155 | 35.78 | 400 | DCI | 130 | 6.85 | 0.42 | 0.63 | 0.88 |
| P-156 | 59.45 | 100 | PVC | 150 | 10.52 | 0.52 | 0.21 | 0.47 |
| P-157 | 80.14 | 100 | PVC | 150 | 1.45 | 0.01 | 0.15 | 0.49 |
| P-158 | 10063 | 100 | PVC | 150 | 5.12 | 0.09 | 3.52 | 0.06 |

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|---|---|---|---|---|---|---|---|---|
| P-159 | 120.35 | 100 | PVC | 150 | 6.15 | 0.58 | 3.96 | 0.29 |
| P-160 | 90.21 | 100 | PVC | 150 | -0.76 | 0.74 | 0.65 | 0.17 |
| P-161 | 60.25 | 100 | PVC | 150 | -0.27 | 0.63 | 0.09 | 0.06 |
| P-162 | 100.87 | 100 | PVC | 150 | -22.96 | 0.51 | 23.15 | 5.2 |
| P-163 | 150.89 | 100 | PVC | 150 | -8.99 | 0.98 | 63.5 | 2.03 |
| P-164 | 104.54 | 200 | PVC | 150 | 27.17 | 0.41 | 30.54 | 0.26 |
| P-165 | 150.23 | 200 | PVC | 150 | 10.25 | 0.57 | 0.25 | 0.005 |
| P-166 | 80.65 | 200 | PVC | 150 | 2.29 | 0.12 | 0.96 | 0.66 |
| P-167 | 75.45 | 200 | PVC | 150 | 15.88 | 0.37 | 0.59 | 0.94 |
| P-168 | 100.98 | 200 | PVC | 150 | 4.15 | 0.16 | 0.23 | 2.6 |
| P-169 | 100.54 | 200 | PVC | 150 | 10.25 | 0.51 | 2.15 | 2.78 |
| P-170 | 109.54 | 200 | PVC | 150 | 11.25 | 0.53 | 2.36 | 0.17 |
| P-171 | 110.78 | 200 | PVC | 150 | 11.56 | 0.61 | 4.23 | 0.22 |
| P-172 | 65.21 | 250 | PVC | 150 | -0.38 | 0.72 | 4.32 | 0.77 |
| P-173 | 105.23 | 250 | PVC | 150 | 5.35 | 0.92 | 4.85 | 0.51 |
| P-174 | 150.26 | 250 | PVC | 150 | 9.45 | 0.85 | 4.05 | 0.81 |
| P-175 | 80.56 | 250 | PVC | 150 | 14.56 | 0.46 | 0.52 | 4.56 |
| P-176 | 85.63 | 250 | PVC | 150 | 14.12 | 0.17 | 0.63 | 0.65 |
| P-177 | 156.24 | 250 | PVC | 150 | -1.88 | 0.59 | 0.21 | 3.84 |
| P-178 | 100.59 | 250 | PVC | 150 | -10.07 | 0.62 | 0.15 | 2.28 |
| P-179 | 80.63 | 250 | PVC | 150 | 10.25 | 0.37 | 0.02 | 0.03 |
| P-180 | 75.12 | 250 | PVC | 150 | 10.63 | 0.05 | 2.52 | 1.32 |
| P-181 | 65.24 | 250 | PVC | 150 | 10.75 | 0.09 | 2.37 | 3.07 |
| P-182 | 100.63 | 250 | PVC | 150 | 17.68 | 0.08 | 2.48 | 2.65 |
| P-183 | 80.78 | 250 | PVC | 150 | 1.42 | 0.06 | 0.63 | 0.32 |
| P-184 | 89.53 | 250 | PVC | 150 | 12.63 | 0.03 | 0.31 | 1.16 |
| P-185 | 45.65 | 250 | HDPE | 120 | 13.52 | 0.04 | 0.48 | 1.26 |
| P-186 | 65.21 | 100 | HDPE | 120 | 12.87 | 0.01 | 0.96 | 0.06 |
| P-187 | 110.96 | 100 | HDPE | 120 | 12.75 | 7.5 | 0.26 | 0.39 |
| P-188 | 100.56 | 100 | HDPE | 120 | 7.15 | 4.16 | 1.58 | 0.98 |
| P-189 | 120.52 | 100 | HDPE | 120 | 10.25 | 0.29 | 1.46 | 0.65 |
| P-190 | 100.78 | 100 | HDPE | 120 | -0.03 | 0.1 | 0.45 | 0.45 |
| P-191 | 80.65 | 100 | HDPE | 120 | -15.8 | 0.06 | 5.65 | 0.65 |
| P-192 | 70.25 | 100 | HDPE | 120 | -11 | 0.7 | 6.25 | 0.32 |
| P-193 | 75.63 | 100 | HDPE | 120 | 0.57 | 8.02 | 0.25 | 0.77 |
| P-194 | 52.21 | 100 | HDPE | 120 | -0.77 | 35.3 | 0.19 | 1.57 |
| P-195 | 125.63 | 100 | HDPE | 120 | 0.4 | 0.09 | 0.63 | 0.83 |
| P-196 | 80.12 | 100 | HDPE | 120 | 4.3 | 0.01 | 0.78 | 0.97 |
| P-197 | 100.96 | 350 | PVC | 150 | -0.81 | 0.03 | 0.65 | 0.61 |
| P-198 | 145.24 | 350 | PVC | 150 | 10.23 | 0 | 0.23 | 0.84 |
| P-199 | 85.35 | 350 | PVC | 150 | -10.31 | 0 | 0.56 | 0.74 |

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|---|---|---|---|---|---|---|---|---|
| P-200 | 56.25 | 350 | PVC | 150 | -10.49 | 0 | 0.15 | 0.93 |
| P-201 | 32.25 | 350 | PVC | 150 | -15.6 | 0 | 0.65 | 3.53 |
| P-202 | 30.58 | 350 | PVC | 150 | 7.29 | 0 | 0.78 | 1.65 |
| P-203 | 41.65 | 350 | PVC | 150 | 0.28 | 16.12 | 0.1 | 0.06 |
| P-204 | 85.12 | 150 | PVC | 150 | 0.56 | 10.52 | 0.37 | 0.13 |
| P-205 | 102.35 | 150 | PVC | 150 | 9.89 | 0.8 | 1.41 | 2.24 |
| P-206 | 105.26 | 150 | PVC | 150 | 9.71 | 0.14 | 1.63 | 2.2 |
| P-207 | 85.36 | 150 | PVC | 150 | 5.85 | 2.06 | 7.76 | 0.77 |
| P-208 | 45.12 | 150 | PVC | 150 | 0.54 | 0.09 | 0.35 | 0.12 |
| P-209 | 75.25 | 150 | PVC | 150 | 12.52 | 0.43 | 4.62 | 0.58 |
| P-210 | 85.15 | 150 | PVC | 150 | 16.52 | 0.23 | 0.02 | 1 |
| P-211 | 80.63 | 150 | PVC | 150 | 10.26 | 1.62 | 0.09 | 0.54 |
| P-212 | 84.65 | 150 | PVC | 150 | 10.56 | 0.67 | 0.5 | 0.52 |
| P-213 | 65.12 | 150 | PVC | 150 | -0.9 | 0.19 | 0.3 | 0.2 |
| P-214 | 58.26 | 100 | PVC | 150 | 6.18 | 1.45 | 0.78 | 1.4 |
| P-215 | 65.32 | 100 | PVC | 150 | 0.52 | 0.1 | 0.32 | 0.12 |
| P-216 | 65.12 | 100 | PVC | 150 | 4.87 | 0.07 | 0.07 | 1.1 |
| P-217 | 86.12 | 100 | PVC | 150 | 14.58 | 0.04 | 0.03 | 1.71 |
| P-218 | 105.26 | 100 | PVC | 150 | 10.65 | 0.08 | 0.05 | 0.55 |
| P-219 | 25.36 | 100 | PVC | 150 | 7.72 | 0.07 | 0.09 | 1.75 |
| P-220 | 52.63 | 100 | PVC | 150 | 10.98 | 0.71 | 2.16 | 0.62 |
| P-221 | 89.56 | 100 | PVC | 150 | 0.8 | 0 | 0.06 | 0.02 |
| P-222 | 19.25 | 100 | PVC | 150 | 4.55 | 1.8 | 0.52 | 1.03 |
| P-223 | 36.21 | 100 | PVC | 150 | 0.17 | 0.01 | 0.96 | 0.04 |
| P-224 | 45.25 | 100 | PVC | 150 | 4.06 | 2.92 | 0.13 | 0.92 |
| P-225 | 48.25 | 100 | PVC | 150 | 0.6 | 22.19 | 0.03 | 1.22 |
| P-226 | 102.56 | 100 | PVC | 150 | 1.72 | 0 | 0.01 | 3.01 |
| P-227 | 105.26 | 100 | PVC | 150 | 0.16 | 0 | 0.08 | 0.33 |
| P-228 | 100.65 | 100 | PVC | 150 | 10.52 | 0 | 0.05 | 0.65 |
| P-229 | 16.5 | 100 | PVC | 150 | 5.78 | 0 | 0.04 | 0.47 |
| P-230 | 56.12 | 100 | PVC | 150 | 0.95 | 0 | 0.25 | 0.11 |
| P-231 | 26.65 | 250 | PVC | 150 | 0.85 | 0 | 3.96 | 1.05 |
| P-232 | 89.75 | 250 | PVC | 150 | 8.25 | 0 | 3.54 | 2.93 |
| P-233 | 100.58 | 250 | PVC | 150 | 6.45 | 0 | 3.78 | 0.24 |
| P-234 | 45.31 | 250 | PVC | 150 | 6.51 | 0 | 3.21 | 1.46 |
| P-235 | 63.25 | 250 | PVC | 150 | 1.62 | 0 | 3.25 | 3.06 |
| P-236 | 45.12 | 250 | PVC | 150 | 1.8 | 0.05 | 3.87 | 6.09 |
| P-237 | 56.25 | 250 | PVC | 150 | 12.52 | 0.09 | 3.95 | 0.54 |
| P-238 | 80.25 | 250 | PVC | 150 | 5.45 | 0.04 | 3.15 | 1.62 |
| P-239 | 105.65 | 80 | HDPE | 120 | 1.29 | 0.07 | 3.59 | 2.63 |
| P-240 | 65.23 | 80 | HDPE | 120 | 0.9 | 0.01 | 3.45 | 1.25 |

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|---|---|---|---|---|---|---|---|---|
| P-241 | 100.26 | 80 | HDPE | 120 | 0.87 | 0.09 | 3.62 | 0.55 |
| P-242 | 105.56 | 80 | HDPE | 120 | 15.78 | 0.08 | 3.24 | 7.55 |
| P-243 | 120.36 | 80 | HDPE | 120 | 10.12 | 0.07 | 3.16 | 2.15 |
| P-244 | 25.65 | 80 | HDPE | 120 | 1.58 | 0.02 | 2.56 | 3.56 |
| P-245 | 65.25 | 80 | HDPE | 120 | 0.89 | 1.25 | 2.81 | 0.99 |
| P-246 | 109.36 | 80 | HDPE | 120 | -0.25 | 2.08 | 2.49 | 0.13 |
| P-247 | 130.89 | 80 | HDPE | 120 | 3.51 | 0.45 | 2.67 | 1.91 |
| P-248 | 65.89 | 80 | HDPE | 120 | 0.61 | 0.96 | 2.59 | 1.24 |
| P-249 | 87.45 | 80 | HDPE | 120 | 2.5 | 0.28 | 0.09 | 0.001 |
| P-250 | 109.25 | 80 | HDPE | 120 | 15.12 | 0.49 | 0.06 | 0.93 |
| P-251 | 100.96 | 80 | HDPE | 120 | 0.85 | 0.46 | 0.07 | 0.67 |
| P-252 | 98.25 | 80 | HDPE | 120 | 0.78 | 0.16 | 0.02 | 0.74 |
| P-253 | 65.25 | 80 | HDPE | 120 | 0.52 | 1.08 | 0.8 | 0.38 |
| P-254 | 65.36 | 80 | HDPE | 120 | 12.36 | 0.56 | 0.7 | 0.7 |
| P-255 | 80.12 | 150 | HDPE | 120 | 12.56 | 0.49 | 0.94 | 0.94 |
| P-256 | 45.21 | 150 | HDPE | 120 | 0.54 | 0.41 | 0.67 | 0.56 |
| P-257 | 98.25 | 150 | HDPE | 120 | 8.12 | 0.06 | 0.65 | 0.35 |
| P-258 | 65.25 | 150 | HDPE | 120 | 15.63 | 0.08 | 0.63 | 0.88 |
| P-259 | 108.75 | 150 | HDPE | 120 | 20.15 | 0 | 0.47 | 0.49 |
| P-260 | 120.39 | 150 | HDPE | 120 | 0.65 | 0 | 0.74 | 2.03 |
| P-261 | 105.65 | 150 | HDPE | 120 | 0.85 | 0 | 0.45 | 0.44 |
| P-262 | 25.65 | 150 | HDPE | 120 | -0.46 | 0 | 0.9 | 0.93 |
| P-263 | 107.26 | 150 | HDPE | 120 | -0.72 | 0.16 | 0.12 | 1.47 |
| P-264 | 150.32 | 150 | HDPE | 120 | -0.4 | 0.35 | 0.65 | 0.82 |
| P-265 | 26.53 | 150 | HDPE | 120 | -3.33 | 0.76 | 0.32 | 1.59 |
| P-266 | 85.14 | 150 | HDPE | 120 | 0.13 | 0.98 | 0.64 | 0.27 |
| P-267 | 95.25 | 100 | HDPE | 120 | 0.33 | 0.18 | 0.98 | 0.67 |
| P-268 | 36.12 | 100 | HDPE | 120 | 10.52 | 0.06 | 0.09 | 0.23 |
| P-269 | 48.15 | 100 | HDPE | 120 | 25.12 | 14.77 | 0.06 | 0.59 |
| P-270 | 65.27 | 100 | HDPE | 120 | 2.56 | 5.58 | 0.05 | 0.47 |
| P-271 | 104.16 | 100 | HDPE | 120 | 10.25 | 26.63 | 0.09 | 4.99 |
| P-272 | 75.26 | 100 | HDPE | 120 | 12.85 | 17.04 | 0.06 | 3.17 |
| P-273 | 100.29 | 100 | HDPE | 120 | 0.85 | 0.36 | 0.05 | 3.62 |
| P-274 | 103.45 | 200 | PVC | 150 | 1.6 | 0.25 | 0.03 | 3.26 |
| P-275 | 85.16 | 200 | PVC | 150 | 3.88 | 0.85 | 0.09 | 0.69 |
| P-276 | 89.14 | 200 | PVC | 150 | 1.66 | 0.42 | 0.01 | 0.009 |
| P-277 | 14.98 | 200 | PVC | 150 | 4.06 | 0.21 | 23.56 | 0.00 |
| P-278 | 102.8 | 200 | PVC | 150 | -0.84 | 0.56 | 165.31 | 0.65 |
| P-279 | 100.49 | 200 | PVC | 150 | -0.64 | 25.23 | 100.91 | 1.31 |
| P-280 | 36.87 | 200 | PVC | 150 | -1.1 | 0 | 0.04 | 0.00 |
| P-281 | 108.26 | 200 | PVC | 150 | -0.78 | 0.65 | 143.68 | 1.58 |

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|---|---|---|---|---|---|---|---|---|
| P-282 | 80.15 | 200 | PVC | 150 | 5.95 | 0.75 | 57.13 | 0.96 |
| P-283 | 75.29 | 200 | PVC | 150 | 5.45 | 0.02 | 0.04 | 0.00 |
| P-284 | 130.89 | 500 | DCI | 130 | 14.75 | 0.01 | 0.1 | 0.1 |
| P-285 | 25.65 | 500 | DCI | 130 | 13.41 | 0.13 | 0.37 | 0.2 |
| P-286 | 158.26 | 500 | DCI | 130 | 10.52 | 0 | 70.49 | 3.12 |
| P-287 | 148.13 | 500 | DCI | 130 | 10.89 | 0 | 12.56 | 3.5 |
| P-288 | 100.25 | 500 | DCI | 130 | 0.93 | 0 | 3.58 | 0.56 |
| P-289 | 50.32 | 500 | DCI | 130 | 5.12 | 0 | 0.09 | 0.75 |
| P-290 | 85.25 | 500 | DCI | 130 | 14.12 | 4.82 | 0.04 | 0.96 |
| P-291 | 89.15 | 500 | DCI | 130 | 0.56 | 0.51 | 0.03 | 0.12 |
| P-292 | 100.89 | 80 | HDPE | 120 | 15.96 | 0.76 | 1.91 | 0.15 |
| P-293 | 80.96 | 80 | HDPE | 120 | 0.68 | 8.9 | 1.65 | 1.38 |
| P-294 | 65.25 | 80 | HDPE | 120 | -0.07 | 0.46 | 1.85 | 0.15 |
| P-295 | 120.58 | 80 | HDPE | 120 | -0.82 | 0.25 | 1.32 | 1.68 |
| P-296 | 89.26 | 80 | HDPE | 120 | 2.56 | 0.85 | 1.68 | 5.21 |
| P-297 | 150.85 | 80 | HDPE | 120 | 0.68 | 0.09 | 0.39 | 0.14 |
| P-298 | 56.26 | 200 | PVC | 150 | 0.14 | 1.58 | 6.32 | 0.29 |
| P-299 | 98.65 | 200 | PVC | 150 | -0.03 | 0.12 | 0.36 | 0.00 |
| P-300 | 47.15 | 200 | PVC | 150 | -1.03 | 0 | 5.21 | 2.1 |
| P-301 | 84.15 | 200 | PVC | 150 | 7.8 | 0.93 | 1.67 | 0.44 |
| P-302 | 85.14 | 200 | PVC | 150 | 7.05 | 0.59 | 1.28 | 0.39 |
| P-303 | 89.26 | 200 | PVC | 150 | 6.73 | 0.23 | 1.17 | 0.37 |
| P-304 | 67.15 | 200 | PVC | 150 | 15.85 | 0.45 | 0.93 | 0.32 |
| P-305 | 60.25 | 200 | PVC | 150 | 10.52 | 0.11 | 0.46 | 0.22 |
| P-306 | 105.69 | 200 | PVC | 150 | 6.25 | 0.44 | 1.74 | 0.35 |
| P-307 | 100.25 | 200 | PVC | 150 | 8.01 | 0.18 | 1.75 | 0.45 |
| P-308 | 56.36 | 200 | PVC | 150 | 11.76 | 0.71 | 3.57 | 0.67 |
| P-309 | 150.25 | 200 | PVC | 150 | 7.76 | 0.25 | 1.65 | 0.44 |
| P-310 | 69.32 | 150 | PVC | 150 | -0.25 | 0.01 | 0.06 | 0.00 |
| P-311 | 80.12 | 150 | PVC | 150 | 6.76 | 0.1 | 1.28 | 0.38 |
| P-312 | 75.15 | 150 | PVC | 150 | -1.55 | 0.05 | 0.6 | 0.2 |
| P-313 | 98.13 | 150 | PVC | 150 | -1.67 | 0.14 | 0.69 | 0.21 |
| P-314 | 90.25 | 150 | HDPE | 120 | 1.51 | 0.01 | 0.08 | 0.00 |
| P-315 | 65.26 | 150 | HDPE | 120 | -4.26 | 0.05 | 0.54 | 0.24 |
| P-316 | 120.25 | 150 | HDPE | 120 | -5.47 | 0.75 | 6.24 | 0.7 |
| P-317 | 102.65 | 150 | HDPE | 120 | 2.58 | 0.55 | 4.6 | 0.51 |
| P-318 | 56.15 | 150 | HDPE | 120 | 1.91 | 0.01 | 0.12 | 0.11 |
| P-319 | 96.36 | 150 | HDPE | 120 | 1.21 | 0.01 | 0.05 | 0.07 |
| P-320 | 87.12 | 150 | HDPE | 120 | 0.26 | 0.01 | 0.07 | 0.005 |
| P-321 | 100.56 | 150 | HDPE | 120 | 12.5 | 1.59 | 15.86 | 0.48 |
| P-322 | 96.26 | 150 | HDPE | 120 | 14.16 | 36.93 | 0.8 | 1.81 |

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|---|---|---|---|---|---|---|---|---|
| P-323 | 49.87 | 150 | HDPE | 120 | -1.28 | 2.5 | 0.6 | 2.6 |
| P-324 | 90.36 | 150 | HDPE | 120 | -0.81 | 0.11 | 0.54 | 0.16 |
| P-325 | 110.89 | 150 | HDPE | 120 | 5.32 | 0.71 | 5.93 | 7.54 |
| P-326 | 80.45 | 150 | HDPE | 120 | -4.27 | 0.31 | 3.94 | 0.54 |
| P-327 | 69.32 | 150 | HDPE | 120 | -0.61 | 6.81 | 3.6 | 1.23 |
| P-328 | 78.52 | 150 | HDPE | 120 | 10.81 | 2.2 | 2.57 | 1.38 |

**Annexes- H2**: Junctions pressure result; during average day demand

| Label | Elevation (m) | Demand (Calculated) (l/s) | Calculated Hydraulic Grade (m) | Pressure (m H2O) | Base Flow (l/s) |
|---|---|---|---|---|---|
| J-1 | 1,900.00 | 0.5 | 1,277.76 | 77.6 | 0.5 |
| J-2 | 2,140.00 | 0.2 | 1,226.26 | 26.21 | 0.2 |
| J-3 | 2,000.00 | 0.14 | 1,946.09 | 46 | 0.14 |
| J-4 | 2,148.25 | 0.04 | 2,378.36 | 0.86 | 0.05 |
| J-5 | 1,995.00 | 0.5 | 1,797.43 | 97.23 | 0.5 |
| J-6 | 2,111.25 | 0.9 | 1,227.06 | 27.01 | 0.9 |
| J-7 | 1,890.00 | 0.5 | 1,284.74 | 84.57 | 0.5 |
| J-8 | 1,900.00 | 0.75 | 1,284.75 | 84.58 | 0.75 |
| J-9 | 2,100.00 | 0.08 | 2,320.96 | 95.77 | 0.08 |
| J-10 | 1,900.00 | 0.8 | 1,912.64 | 12.62 | 0.8 |
| J-11 | 1,885.00 | 0.14 | 2,322.11 | 2.11 | 0.14 |
| J-12 | 2,000.00 | 0.2 | 1,982.06 | 81.9 | 0.2 |
| J-13 | 1,900.00 | 0.16 | 1,981.42 | 81.25 | 0.16 |
| J-14 | 2,000.00 | 0.18 | 1,981.39 | 81.22 | 0.18 |
| J-15 | 2,100.00 | 0.14 | 1,947.35 | 47.26 | 0.14 |
| J-16 | 2,100.00 | 0.14 | 1,912.53 | 12.5 | 0.14 |
| J-17 | 1,900.75 | 0.18 | 1,296.39 | 96.19 | 0.18 |
| J-18 | 2,115.00 | 0.18 | 1,981.49 | 81.32 | 0.18 |
| J-19 | 1,995.00 | 0.14 | 1,899.15 | -0.84 | 0.14 |
| J-20 | 2,000.00 | 0.14 | 1,912.99 | 12.96 | 0.14 |
| J-21 | 1,885.00 | 0.14 | 1,259.58 | 59.46 | 0.14 |
| J-22 | 1,950.00 | 0.14 | 2,321.58 | 305 | 0.14 |
| J-23 | 1,800.00 | 0.14 | 2,322.98 | 22.93 | 0.14 |
| J-24 | 1,900.00 | 0.18 | 1,959.78 | 59.66 | 0.18 |
| J-25 | 2,000.00 | 0.14 | 1,270.02 | 69.88 | 0.14 |
| J-26 | 2,000.00 | 0.13 | 1,991.27 | 91.09 | 0.13 |
| J-27 | 1,900.00 | 0.14 | 1,278.27 | 78.11 | 0.14 |
| J-28 | 1,900.00 | 0.14 | 1,269.64 | 69.5 | 0.14 |
| J-29 | 2,110.00 | 0.14 | 2,176.23 | 66.09 | 0.14 |
| J-30 | 1,900.00 | 0.09 | 1,285.90 | 85.73 | 0.09 |

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|---|---|---|---|---|---|
| J-31 | 1,900.00 | 0.18 | 1,897.93 | 97.73 | 0.18 |
| J-32 | 2,040.00 | 0.14 | 2,040.60 | 0.6 | 0.14 |
| J-33 | 1,900.00 | 0.25 | 1,899.21 | 9.19 | 0.25 |
| J-34 | 1,895.00 | 0.14 | 1,997.27 | 97.07 | 0.14 |
| J-35 | 2,100.00 | 0.09 | 1,218.76 | 18.72 | 0.09 |
| J-36 | 2,000.00 | 0.09 | 1,281.98 | 81.81 | 0.09 |
| J-37 | 2,000.00 | 0.18 | 1,287.84 | 87.66 | 0.18 |
| J-38 | 1,800.00 | 0.16 | 2,013.47 | 13.44 | 0.16 |
| J-39 | 1,990.00 | 0.18 | 1,227.07 | 27.01 | 0.18 |
| J-40 | 1,800.00 | 0.25 | 1,285.08 | 84.91 | 0.25 |
| J-41 | 1,750.00 | 0.14 | 2,327.14 | 15.11 | 0.14 |
| J-42 | 1,995.00 | 0.14 | 1,256.29 | 56.18 | 0.14 |
| J-43 | 2,000.00 | 0.14 | 1,284.73 | 84.56 | 0.14 |
| J-44 | 1,700.00 | 0.18 | 1,269.83 | 69.68 | 0.18 |
| J-45 | 1,750.00 | 0.18 | 1,284.88 | 84.71 | 0.18 |
| J-46 | 2,100.00 | 0.5 | 1,290.15 | 89.97 | 0.5 |
| J-47 | 2,000.00 | 0.14 | 1,917.59 | 17.56 | 0.14 |
| J-48 | 2,100.00 | 0.2 | 1,276.17 | 76.01 | 0.2 |
| J-49 | 2,000.00 | 0.14 | 1,920.39 | 20.35 | 0.14 |
| J-50 | 2,000.00 | 0.18 | 1,267.52 | 67.38 | 0.18 |
| J-51 | 2,100.00 | 0.09 | 2068.42 | 8.4 | 0.09 |
| J-52 | 2,100.00 | 0.09 | 2,129.13 | 29.07 | 0.09 |
| J-53 | 1,900.00 | 0.09 | 1,313.00 | 12.97 | 0.09 |
| J-54 | 2,000.00 | 0.25 | 1,256.00 | 55.89 | 0.25 |
| J-55 | 2,000.00 | 0.09 | 1,892.55 | 7.53 | 0.09 |
| J-56 | 2,000.00 | 0.09 | 2,128.33 | 28.27 | 0.09 |
| J-57 | 2,120.00 | 0.14 | 1,852.54 | 52.43 | 0.14 |
| J-58 | 2,000.00 | 0.14 | 1,850.16 | 50.06 | 0.14 |
| J-59 | 2,000.00 | 0.14 | 1,891.65 | 91.46 | 0.14 |
| J-60 | 2,105.00 | 0.09 | 2,109.01 | 8.99 | 0.09 |
| J-61 | 1,925.00 | 0.14 | 1,976.86 | 76.71 | 0.14 |
| J-62 | 2,000.00 | 0.14 | 1,202.87 | 2.86 | 0.14 |
| J-63 | 2,040.00 | 0.18 | 1,310.47 | 110.25 | 0.18 |
| J-64 | 2,000.00 | 0.14 | 1,346.99 | 146.7 | 0.14 |
| J-65 | 2,100.00 | 0.09 | 2,163.19 | 63.06 | 0.09 |
| J-66 | 1,885.00 | 0.09 | 1,230.21 | 30.15 | 0.09 |
| J-67 | 2,130.00 | 0.09 | 1,234.28 | 34.21 | 0.09 |
| J-68 | 2,130.00 | 0.09 | 2,110.02 | 10 | 0.09 |
| J-69 | 2,000.00 | 0.25 | 1,920.51 | 20.47 | 0.25 |
| J-70 | 2,100.00 | 0.14 | 1,848.99 | 48.89 | 0.14 |
| J-71 | 1,900.00 | 0.18 | 1,951.53 | 51.42 | 0.18 |

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|---|---|---|---|---|---|
| J-72 | 2,100.00 | 0.2 | 1,252.29 | 52.19 | 0.2 |
| J-73 | 2,130.00 | 0.16 | 1,822.56 | 22.51 | 0.16 |
| J-74 | 2,000.00 | 0.09 | 2,160.32 | 60.2 | 0.09 |
| J-75 | 2,000.00 | 0.09 | 2,064.07 | 63.94 | 0.09 |
| J-76 | 1,750.00 | 0.23 | 1,255.72 | 55.6 | 0.23 |
| J-77 | 1,890.00 | 0.14 | 1,897.41 | 97.21 | 0.14 |
| J-78 | 1,700.00 | 1 | 1,877.04 | 76.89 | 0.23 |
| J-79 | 1,990.00 | 0.14 | 1,226.43 | 26.38 | 0.14 |
| J-80 | 2,135.00 | 0.18 | 1,226.26 | 26.21 | 0.18 |
| J-81 | 1,950.00 | 0.14 | 2,061.79 | 61.66 | 0.14 |
| J-82 | 1,700.00 | 0.14 | 1,976.88 | 76.72 | 0.14 |
| J-83 | 2,000.00 | 0.14 | 1,364.47 | 164.14 | 0.14 |
| J-84 | 2,010.00 | 0.09 | 2,048.47 | 48.37 | 0.09 |
| J-85 | 2,000.00 | 0.14 | 2,000.89 | 0.89 | 0.14 |
| J-86 | 2,000.00 | 0.18 | 1,579.61 | 79.45 | 0.18 |
| J-87 | 2,100.00 | 1 | 2,331.45 | 1.45 | 0.04 |
| J-88 | 2,000.00 | 0.09 | 1,852.13 | 52.02 | 0.09 |
| J-89 | 2,100.00 | 0.09 | 2,208.25 | 108.03 | 0.09 |
| J-90 | 2,000.00 | 0.14 | 1,853.01 | 52.91 | 0.14 |
| J-91 | 1,750.00 | 0.09 | 1,847.92 | 47.83 | 0.09 |
| J-92 | 1,700.00 | 0.09 | 1,847.20 | 47.11 | 0.09 |
| J-93 | 1,900.00 | 0.09 | 1,838.41 | 38.33 | 0.09 |
| J-94 | 1,990.00 | 0.18 | 1,877.82 | 77.67 | 0.18 |
| J-95 | 2,000.00 | 0.14 | 1,427.69 | 27.63 | 0.14 |
| J-96 | 2,000.00 | 0.09 | 2,048.06 | 47.96 | 0.09 |
| J-97 | 1,900.00 | 0.09 | 2,008.45 | 8.44 | 0.09 |
| J-98 | 2,115.00 | 0.18 | 1,543.75 | 43.66 | 0.18 |
| J-99 | 2,000.00 | 0.14 | 1,858.99 | 58.88 | 0.14 |
| J-100 | 2,100.00 | 0.09 | 1,857.16 | 57.05 | 0.09 |
| J-101 | 2,100.00 | 0.09 | 1,846.25 | 46.16 | 0.09 |
| J-102 | 1,900.00 | 0.09 | 1,846.80 | 46.71 | 0.09 |
| J-103 | 2,100.00 | 0.18 | 1,534.96 | 34.89 | 0.18 |
| J-104 | 2,100.00 | 0.23 | 1,778.92 | 78.76 | 0.23 |
| J-105 | 1,885.00 | 0.09 | 2,198.72 | 198.32 | 0.09 |
| J-106 | 1,900.00 | 0.09 | 1,833.57 | 33.5 | 0.09 |
| J-107 | 2,115.25 | 0.2 | 1,226.26 | 26.2 | 0.2 |
| J-108 | 1,700.00 | 0.09 | 1,852.85 | 52.74 | 0.09 |
| J-109 | 2,120.00 | 0.18 | 1,560.03 | 59.91 | 0.18 |
| J-110 | 1,900.00 | 0.25 | 1,532.48 | 32.42 | 0.25 |
| J-111 | 1,900.00 | 0.18 | 1,238.12 | 38.05 | 0.18 |
| J-112 | 2,100.00 | 0.14 | 1,851.29 | -1.61 | 0.14 |

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|---|---|---|---|---|---|
| J-113 | 1,800.00 | 0.09 | 1,848.77 | 48.67 | 0.09 |
| J-114 | 1,750.00 | 0.09 | 1,848.53 | 48.43 | 0.09 |
| J-115 | 1,900.00 | 0.14 | 1,984.30 | 84.13 | 0.14 |
| J-116 | 1,800.00 | 0.13 | 1,984.29 | 183.92 | 0.13 |
| J-117 | 1,800.00 | 0.23 | 1,976.91 | -3.05 | 0.23 |
| J-118 | 2,120.00 | 0.2 | 1,800.37 | 0.37 | 0.2 |
| J-119 | 1,950.00 | 0.2 | 1,955.77 | 55.65 | 0.2 |
| J-120 | 1,928.00 | 0.2 | 1,852.82 | 52.72 | 0.2 |
| J-121 | 2,000.00 | 0.16 | 1,870.88 | 170.53 | 0.16 |
| J-122 | 2,100.00 | 0.09 | 1,817.53 | 17.49 | 0.09 |
| J-123 | 2,000.00 | 8.07 | 1726.38 | -2.56 | 8.07 |
| J-124 | 2,000.00 | 0.18 | 1,480.65 | 80.49 | 0.18 |
| J-125 | 2,000.00 | 0.18 | 1,522.70 | 22.65 | 0.18 |
| J-126 | 2,115.00 | 0.16 | 1,194.00 | -1.78 | 0.16 |
| J-127 | 2,000.00 | 0.14 | 1,849.08 | 48.98 | 0.14 |
| J-128 | 1,900.00 | 0.25 | 1,727.52 | 27.47 | 0.25 |
| J-129 | 1,900.00 | 0.09 | 1,859.57 | 59.45 | 0.09 |
| J-130 | 2,120.00 | 0.18 | 2,107.66 | 107.44 | 0.18 |
| J-131 | 1,800.00 | 0.14 | 1,855.07 | 54.96 | 0.14 |
| J-132 | 2,000.00 | 0.14 | 1,469.02 | -0.81 | 0.14 |
| J-133 | 1,985.00 | 0.14 | 1,459.98 | 59.86 | 0.14 |
| J-134 | 1,900.00 | 0.14 | 1,491.40 | 91.22 | 0.14 |
| J-135 | 2,000.00 | 0.18 | 1,591.39 | 91.21 | 0.18 |
| J-136 | 2,110.00 | 0.09 | 1,849.00 | 48.9 | 0.09 |
| J-137 | 2,000.00 | 0.14 | 1,849.08 | 48.98 | 0.14 |
| J-138 | 1,800.00 | 0.23 | 1,240.64 | -0.21 | 0.23 |
| J-139 | 1,900.00 | 0.09 | 1,232.80 | 32.73 | 0.09 |
| J-140 | 2,121.00 | 0.09 | 1,154.93 | -1.84 | 0.09 |
| J-141 | 2,000.00 | 0.8 | 1890.68 | -1.74 | 0.8 |
| J-142 | 2,125.00 | 0.14 | 2,205.58 | 304.97 | 0.14 |
| J-143 | 2,115.00 | 0.09 | 1,850.43 | 50.33 | 0.09 |
| J-144 | 2,115.00 | 0.18 | 1,459.98 | 159.66 | 0.18 |
| J-145 | 2,100.00 | 0.23 | 1,481.73 | 281.17 | 0.23 |
| J-146 | 2,100.00 | 0.14 | 1,850.17 | 50.06 | 0.14 |
| J-147 | 1,990.00 | 0.25 | 1,522.18 | 22.14 | 0.25 |
| J-148 | 1,900.00 | 0.09 | 1,458.72 | -3.4 | 0.09 |
| J-149 | 1,870.00 | 0.23 | 1,797.49 | 97.29 | 0.23 |
| J-150 | 1,900.00 | 0.14 | 1,867.92 | 67.79 | 0.14 |
| J-151 | 1,900.00 | 0.05 | 1925.34 | 205.15 | 0.05 |
| J-152 | 2,100.00 | 0.09 | 1,869.58 | 69.44 | 0.09 |
| J-153 | 2,115.00 | 0.09 | 1,852.61 | 52.5 | 0.09 |

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|---|---|---|---|---|---|
| J-154 | 1,885.00 | 0.14 | 1,852.61 | 152.31 | 0.14 |
| J-155 | 2,000.00 | 0.2 | 1,531.81 | 31.74 | 0.2 |
| J-156 | 1,995.00 | 0.09 | 1,840.10 | 40.02 | 0.09 |
| J-157 | 2,150.00 | 0 | 1,563.25 | 63.13 | 0.09 |
| J-158 | 2,000.00 | 0 | 1,241.63 | 41.54 | 0.18 |
| J-159 | 1,980.00 | 0 | 1,339.65 | 39.57 | 0.14 |
| J-160 | 1,800.00 | 0.14 | 1,764.00 | 63.88 | 0.14 |
| J-161 | 1,800.00 | 0.2 | 1,870.45 | 70.3 | 0.2 |
| J-162 | 2,000.00 | 0.14 | 1,334.64 | 210.18 | 0.14 |
| J-163 | 2,140.00 | 0.14 | 1,334.46 | 134.19 | 0.14 |
| J-164 | 1,995.00 | 0.18 | 1,867.94 | 1.5 | 0.18 |
| J-165 | 1,995.00 | 0.18 | 1,859.31 | 59.19 | 0.18 |
| J-166 | 2,000.00 | 0.18 | 1,868.76 | 68.62 | 0.18 |
| J-167 | 1,900.00 | 0.16 | 1,893.08 | 92.9 | 0.16 |
| J-168 | 2,100.00 | 0.09 | 1,855.80 | 55.69 | 0.09 |
| J-169 | 2,000.00 | 0.09 | 1,855.60 | 105.39 | 0.09 |
| J-170 | 2,114.00 | 0.09 | 2,099.88 | 99.68 | 0.09 |
| J-171 | 2,000.00 | 0.14 | 2,060.85 | 60.73 | 0.14 |
| J-172 | 2,115.00 | 0.14 | 2,127.61 | -0.25 | 0.14 |
| J-173 | 2,110.00 | 0.09 | 1,861.77 | 61.64 | 0.09 |
| J-174 | 2,000.00 | 0.09 | 1,860.45 | -3.47 | 0.09 |
| J-175 | 2,000.00 | 0.2 | 2,109.28 | -109.06 | 0.2 |
| J-176 | 1,900.00 | 0.8 | 1,924.50 | 24.45 | 0.08 |
| J-177 | 2,000.00 | 0.14 | 1,912.20 | 111.97 | 0.14 |
| J-178 | 1,900.00 | 0.14 | 1,868.46 | 68.32 | 0.14 |
| J-179 | 2,000.00 | 0.18 | 1,868.65 | -31.29 | 0.18 |
| J-180 | 2,110.00 | 0.2 | 2,114.39 | 114.16 | 0.2 |
| J-181 | 2,100.00 | 0.14 | 2,104.47 | 204.06 | 0.14 |
| J-182 | 2,115.00 | 0.14 | 2,106.01 | 105.79 | 0.14 |
| J-183 | 1,995.00 | 0.14 | 1,903.15 | -2.66 | 0.14 |
| J-184 | 2,000.00 | 0.14 | 1,901.91 | 101.7 | 0.14 |
| J-185 | 1,998.25 | 0.32 | 1,901.01 | 53.12 | 0.32 |
| J-186 | 2,000.00 | 0.25 | 1,897.94 | 197.54 | 0.25 |
| J-187 | 1,900.00 | 0.18 | 1,880.70 | 130.43 | 0.18 |
| J-188 | 2,110.00 | 0.14 | 1,870.84 | 70.7 | 0.14 |
| J-189 | 2,100.00 | 0.14 | 1,868.04 | 167.7 | 0.14 |
| J-190 | 2,000.00 | 0.14 | 2,111.14 | 110.91 | 0.14 |
| J-191 | 2,000.00 | 0.18 | 2,105.18 | 104.97 | 0.18 |
| J-192 | 1,890.00 | 0.05 | 2,105.18 | 5.17 | 0.05 |
| J-193 | 1,995.00 | 0.14 | 2,107.77 | 7.75 | 0.14 |
| J-194 | 1,995.00 | 0.14 | 1,714.06 | 14.03 | 0.14 |

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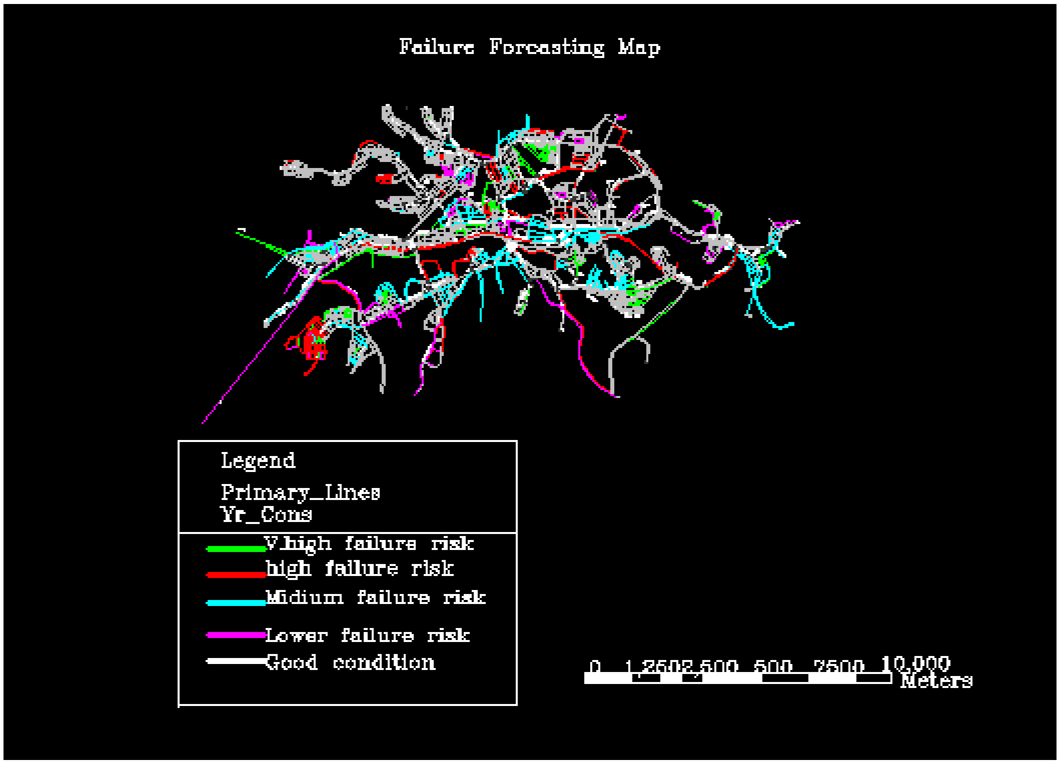
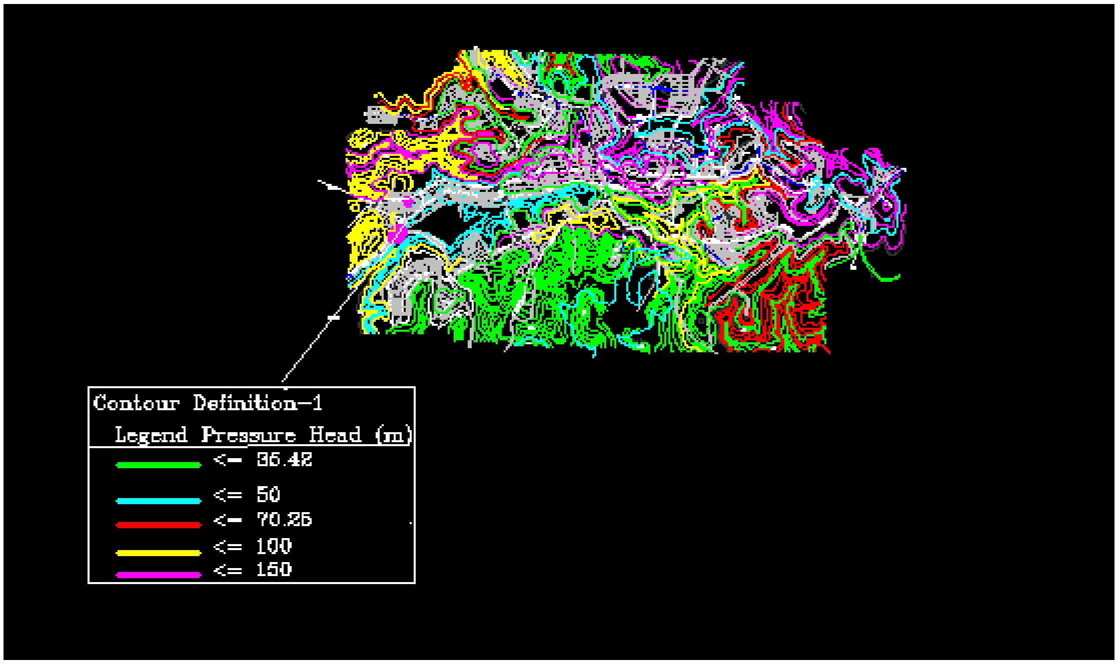
|---|---|---|---|---|---|
| J-195 | 2,000.00 | 0.18 | 1,969.94 | 169.6 | 0.18 |
| J-196 | 1,900.00 | 0 | 1,913.85 | -0.97 | 0.18 |
| J-197 | 2,100.00 | 0 | 2,109.34 | 9.32 | 0.18 |
| J-198 | 1,750.00 | 0 | 1,685.29 | -0.68 | 0.23 |
| J-199 | 2,000.00 | 0.14 | 2,107.78 | 107.56 | 0.14 |
| J-200 | 1,900.00 | 0.14 | 2,106.27 | 205.86 | 0.14 |
| J-201 | 1,800.00 | 0.14 | 1,740.28 | 40.2 | 0.14 |
| J-202 | 1,750.00 | 0.14 | 1,750.20 | 0.2 | 0.14 |
| J-203 | 2,000.00 | 0.14 | 2,106.42 | 106.21 | 0.14 |
| J-204 | 1,900.00 | 0.14 | 1,763.99 | 63.86 | 0.14 |
| J-205 | 2,150.00 | 0.32 | 2,379.77 | 279.21 | 0.32 |
| J-206 | 2,115.00 | 0.85 | 2,362.73 | 162.4 | 0.09 |
| J-207 | 2,100.00 | 0.5 | 2,345.55 | 145.25 | 0.5 |
| J-208 | 1,900.00 | 0.8 | 1,275.46 | 75.31 | 0.8 |
| J-209 | 2,000.00 | 0.06 | 1,279.72 | 79.56 | 0.07 |
| J-210 | 1,890.00 | 0.5 | 1,286.80 | -2.77 | 0.5 |
| J-211 | 1,880.00 | 0.95 | 1,286.66 | 86.49 | 0.95 |
| J-212 | 2,000.00 | 0.75 | 1,238.58 | -1.39 | 0.75 |
| J-213 | 1,750.00 | 0.25 | 1,315.81 | 15.78 | 0.25 |
| J-214 | 1,900.00 | 0.3 | 1,202.78 | 2.77 | 0.3 |
| J-215 | 1,860.00 | 0.8 | 1,201.20 | 1.29 | 0.8 |
| J-216 | 1,800.00 | 0.05 | 1,201.31 | 1.31 | 0.02 |
| J-217 | 2,090.00 | 0.75 | 1,289.22 | 89.04 | 0.75 |
| J-218 | 2,000.00 | 0.32 | 1,288.63 | 88.45 | 0.32 |
| J-219 | 1,950.00 | 0.8 | 1,288.40 | -0.58 | 0.8 |
| J-220 | 1,900.00 | 0.94 | 1,287.95 | -0.02 | 0.94 |
| J-221 | 1,800.00 | 0.54 | 1,287.24 | 87.06 | 0.07 |
| J-222 | 1,750.00 | 0.25 | 1,287.06 | 86.88 | 0.25 |
| J-223 | 1,800.00 | 0.75 | 1,286.81 | 36.74 | 0.75 |
| J-224 | 1,760.00 | 0.95 | 1,286.71 | 6.7 | 0.95 |
| J-225 | 1,850.00 | 0.3 | 1,286.66 | 86.48 | 0.3 |
| J-226 | 1,900.00 | 0.67 | 1,981.51 | 181.14 | 0.67 |
| J-227 | 1,845.00 | 0.7 | 1,981.50 | -1.46 | 0.7 |
| J-228 | 1,800.00 | 0.5 | 1,201.19 | 1.19 | 0.5 |
| J-229 | 1,700.00 | 0.25 | 1,285.19 | 204.89 | 0.25 |
| J-230 | 1,900.00 | 0.8 | 1,286.26 | 84.26 | 0.09 |
| J-231 | 2,100.00 | 0.07 | 1,285.24 | 210.05 | 0.12 |
| J-232 | 1,990.00 | 0.1 | 1,281.56 | 85.15 | 0.45 |
| J-233 | 2,150.00 | 0.25 | 1,285.65 | -0.81 | 0.74 |
| J-234 | 2,050.00 | 0.78 | 1,285.42 | 45.19 | 0.70 |
| J-235 | 1,850.00 | 0.08 | 1,285.47 | 35.12 | 0.49 |

| | | | | | |
|---|---|---|---|---|---|
| J-236 | 1,980.00 | 0.5 | 1,289.21 | 48.24 | 0.95 |
| J-237 | 2,150.00 | 0.48 | 1,281.56 | 51.29 | 0.78 |
| J-238 | 1,950.00 | 0.57 | 1,285.12 | 61.08 | 0.81 |
| J-239 | 1,850.00 | 0.14 | 1,284.27 | -0.91 | 0.43 |
| J-240 | 1,750.00 | 0.75 | 1,281.00 | -0.12 | 0.09 |
| J-241 | 2,050.00 | 0.41 | 1,286.17 | 21.45 | 0.04 |

## Annexes-H3: Failure forecasting map



### Annexes-H4: Contour definition




### WaterGEMS V8i simulation run@4:00, EPS analysis

### Annexes-H5: Pipes EPS analysis result at Peak hour demand

| Label | Length (m) | Diameter (mm) | Material | Hazen-Williams C | Discharge (l/s) | Pressure Pipe Headloss (m) | Headloss Gradient (m/km) | Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|
| P-1 | 85.15 | 80 | PVC | 150 | 8.95 | 0.58 | 0.26 | 1.17 |
| P-2 | 45.62 | 100 | PVC | 150 | 12.96 | 0.08 | 4.15 | 1.5 |
| P-3 | 49.56 | 80 | PVC | 150 | 11.25 | 0.09 | 0.57 | 0.28 |
| P-4 | 51.63 | 150 | PVC | 150 | -1.35 | 1.55 | 0.75 | 0.95 |
| P-5 | 59.16 | 80 | HDPE | 120 | 0.45 | 0.53 | 4.87 | 0.57 |
| P-6 | 85.59 | 300 | HDPE | 120 | 12.24 | 0.06 | 0.47 | 0.85 |
| P-7 | 80.26 | 100 | HDPE | 120 | 11.25 | 0.19 | 4.9 | 0.85 |
| P-8 | 93.52 | 150 | HDPE | 120 | 12.25 | 4.77 | 3.56 | 0.96 |
| P-9 | 45.63 | 300 | PVC | 150 | 15.26 | 1.95 | 3.8 | 2.16 |
| P-10 | 100.85 | 100 | PVC | 150 | 16.15 | 0.09 | 1.52 | 0.06 |
| P-11 | 108.65 | 200 | PNC | 150 | 15.11 | 2.25 | 1.05 | 0.84 |
| P-12 | 49.65 | 100 | PVC | 150 | 17.12 | 0.89 | 3.12 | 4.97 |
| P-13 | 66.52 | 150 | PVC | 150 | 16.13 | 0.15 | 0.75 | 1.63 |
| P-14 | 141.48 | 150 | PVC | 150 | 16.17 | 4.32 | 0.75 | 1.87 |
| P-15 | 51.89 | 300 | PVC | 150 | 11.12 | 0.09 | 1.52 | 2.86 |
| P-16 | 66.36 | 100 | PVC | 150 | 16.78 | 0.9 | 1.48 | 3.42 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| P-17 | 64.78 | 200 | PVC | 150 | 11.32 | 0.96 | 3.25 | 1.95 |
| P-18 | 83.19 | 250 | PVC | 150 | 9.15 | 0.05 | 2.71 | 1.86 |
| P-19 | 58.26 | 250 | PVC | 150 | 12.12 | 0.01 | 3.89 | 0.83 |
| P-20 | 96.25 | 80 | PVC | 150 | 11.98 | 0.06 | 1.63 | 2.44 |
| P-21 | 30.47 | 250 | PVC | 150 | 6.32 | 0 | 1.54 | 0.78 |
| P-22 | 156.25 | 250 | PVC | 150 | 6.05 | 1.00 | 0.58 | 1.26 |
| P-23 | 85.31 | 230 | HDPE | 120 | 0.29 | 0.09 | 0.85 | 0.38 |
| P-24 | 97.23 | 300 | HDPE | 120 | -0.95 | 0.15 | 0.45 | 0.89 |
| P-25 | 120.89 | 200 | HDPE | 120 | 0.45 | 0.47 | 0.45 | 0.56 |
| P-26 | 80.6 | 100 | HDPE | 120 | 13.32 | 0.42 | 0.12 | 0.02 |
| P-27 | 65.2 | 200 | HDPE | 120 | 14.21 | 0.5 | 0.29 | 0.01 |
| P-28 | 84.15 | 400 | DCI | 130 | 14.15 | 0.05 | 16.25 | 0.69 |
| P-29 | 100.78 | 500 | DCI | 130 | 13.63 | 0.95 | 7.22 | 0.42 |
| P-30 | 68.58 | 400 | DCI | 130 | 15.51 | 0.08 | 0.09 | 0.08 |
| P-31 | 95.63 | 400 | DCI | 130 | 15.24 | 1.45 | 3.65 | 0.48 |
| P-32 | 102.56 | 400 | DCI | 130 | 16.15 | 2.08 | 7.78 | 0.75 |
| P-33 | 100.26 | 500 | DCI | 130 | 13.16 | 1.4 | 3.7 | 0.01 |
| P-34 | 85.41 | 400 | DCI | 130 | 15.19 | 0.09 | 0.9 | 0.15 |
| P-35 | 92.56 | 400 | DCI | 130 | 15.81 | 0.09 | 2.52 | 0.29 |
| P-36 | 65.89 | 100 | HDPE | 120 | 10.23 | 0.9 | 2.21 | 0.53 |
| P-37 | 120.65 | 300 | HDPE | 120 | 11.14 | 0.08 | 3.51 | 2.04 |
| P-38 | 150.85 | 300 | HDPE | 120 | 9.12 | 0.9 | 1.51 | 1.75 |
| P-39 | 147.98 | 300 | HDPE | 120 | 0.18 | 0.01 | 2.23 | 0.38 |
| P-40 | 70.65 | 350 | HDPE | 120 | -0.15 | 0.12 | 4.29 | 0.31 |
| P-41 | 63.2 | 250 | HDPE | 120 | 8.25 | 0.45 | 5.19 | 0.54 |
| P-42 | 95.45 | 300 | HDPE | 120 | 0.38 | 0.03 | 4.84 | 0.01 |
| P-43 | 100.62 | 300 | PVC | 150 | -12.17 | 0.04 | 4.58 | 2.6 |
| P-44 | 80.41 | 200 | PVC | 150 | -1.57 | 0.08 | 5.15 | 2.45 |
| P-45 | 56.21 | 100 | PVC | 150 | 2.06 | 0.08 | 0.75 | 3.42 |
| P-46 | 120.87 | 100 | PVC | 150 | -0.15 | 0.00 | 0.45 | 1.76 |
| P-47 | 56.23 | 100 | PVC | 150 | 15.25 | 0.00 | 0.25 | 1.45 |
| P-48 | 130.95 | 100 | PVC | 150 | 1.56 | 0.00 | 0.13 | 0.55 |
| P-49 | 106.89 | 80 | PVC | 150 | 11.89 | 0.00 | 0.15 | 0.12 |
| P-50 | 140.56 | 80 | PVC | 150 | 11.25 | 0.57 | 0.41 | 0.24 |
| P-51 | 120.63 | 80 | PVC | 150 | 5.21 | 0.51 | 144.12 | 2.65 |
| P-52 | 80.5 | 80 | PVC | 150 | 0.94 | 1.25 | 7.06 | 0.48 |
| P-53 | 80.65 | 80 | PVC | 150 | 12.01 | 2.25 | 15.48 | 0.02 |
| P-54 | 80.63 | 200 | PVC | 150 | 5.45 | 1.89 | 3.18 | 0.45 |
| P-55 | 85.45 | 200 | PVC | 150 | 9.23 | 2.54 | 5.21 | 0.47 |
| P-56 | 92.51 | 350 | PVC | 150 | 10.14 | 0.54 | 2.35 | 0.24 |
| P-57 | 100.36 | 350 | PVC | 150 | 2.89 | 0.36 | 22.51 | 1.64 |

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|---|---|---|---|---|---|---|---|---|
| P-58 | 150.49 | 350 | PVC | 150 | 13.12 | 1.85 | 3.15 | 0.91 |
| P-59 | 65.12 | 350 | PVC | 150 | 10.87 | 1.45 | 3.29 | 1.26 |
| P-60 | 52.96 | 150 | PVC | 150 | -0.25 | 0.25 | 2.95 | 0.81 |
| P-61 | 45.65 | 100 | PVC | 150 | -1.25 | 1.85 | 3.41 | 1.61 |
| P-62 | 89.52 | 150 | PVC | 150 | -0.45 | 0.48 | 3.12 | 1.12 |
| P-63 | 25.64 | 150 | PVC | 150 | 11.75 | 0.05 | 4.14 | 0.08 |
| P-64 | 150.56 | 150 | PVC | 150 | 9.26 | 1.54 | 1.56 | 3.14 |
| P-65 | 60.58 | 200 | PVC | 150 | 11.36 | 1.09 | 1.28 | 0.89 |
| P-66 | 125.62 | 150 | PVC | 150 | 10.45 | 0.00 | 0.48 | 1.54 |
| P-67 | 80.14 | 150 | PVC | 150 | 11.25 | 0.00 | 0.56 | 0.48 |
| P-68 | 100.89 | 150 | PVC | 150 | 7.45 | 0.00 | 0.48 | 2.51 |
| P-69 | 95.32 | 150 | PVC | 150 | 13.54 | 0.00 | 5.05 | 0.02 |
| P-70 | 120.75 | 150 | PVC | 150 | 15.46 | 0.00 | 0.45 | 1.24 |
| P-71 | 29.47 | 150 | PVC | 150 | 14.22 | 0.00 | 1.74 | 0.89 |
| P-72 | 100.54 | 150 | PVC | 150 | 7.25 | 0.74 | 0.01 | 0.54 |
| P-73 | 80.42 | 150 | PVC | 150 | 12.10 | 4.41 | 2.69 | 1.05 |
| P-74 | 65.98 | 200 | PVC | 150 | -3.04 | 1.25 | 0.45 | 5.31 |
| P-75 | 90.24 | 200 | PVC | 150 | 9.04 | 0.09 | 0.45 | 1.25 |
| P-76 | 100.45 | 200 | PVC | 150 | 11.14 | 1.15 | 1.25 | 0.48 |
| P-77 | 80.47 | 200 | PVC | 150 | 9.01 | 0.48 | 15.02 | 0.25 |
| P-78 | 106.12 | 200 | PVC | 150 | 0.06 | 0.25 | 45.2 | 1.09 |
| P-79 | 90.45 | 200 | PVC | 150 | 10.12 | 1.05 | 3.76 | 5.12 |
| P-80 | 100.85 | 200 | PVC | 150 | -1.78 | 0.25 | 2.56 | 3.65 |
| P-81 | 60.48 | 200 | PVC | 150 | 14.12 | 1.65 | 2.84 | 1.28 |
| P-82 | 90.65 | 200 | PVC | 150 | 13.87 | 2.45 | 3.85 | 1.52 |
| P-83 | 85.56 | 200 | PVC | 150 | 10.12 | 0.74 | 0.79 | 0.96 |
| P-84 | 75.12 | 100 | HDPE | 120 | 12.01 | 2.15 | 0.49 | 1.25 |
| P-85 | 56.35 | 100 | HDPE | 120 | 13.79 | 1.09 | 1.45 | 1.25 |
| P-86 | 80.25 | 100 | HDPE | 120 | 12.45 | 0.09 | 0.89 | 0.84 |
| P-87 | 100.65 | 100 | HDPE | 120 | 4.99 | 0.47 | 0.84 | 0.05 |
| P-88 | 80.45 | 100 | HDPE | 120 | 15.45 | 1.02 | 1.18 | 4.25 |
| P-89 | 98.65 | 400 | DCI | 130 | 14.42 | 0.08 | 1.24 | 1.75 |
| P-90 | 65.23 | 400 | DCI | 130 | 17.21 | 1.74 | 0.25 | 2.45 |
| P-91 | 120.64 | 400 | DCI | 130 | 11.51 | 0.00 | 0.45 | 4.74 |
| P-92 | 70.47 | 400 | DCI | 130 | 12.36 | 0.00 | 0.47 | 1.52 |
| P-93 | 56.25 | 400 | DCI | 130 | 16.04 | 0.00 | 0.87 | 2.02 |
| P-94 | 100.47 | 400 | DCI | 130 | 16.27 | 0.00 | 3.75 | 1.98 |
| P-95 | 80.64 | 400 | DCI | 130 | 14.35 | 0.00 | 5.75 | 1.98 |
| P-96 | 120.98 | 400 | DCI | 130 | 11.75 | 0.00 | 4.78 | 0.78 |
| P-97 | 50.46 | 400 | DCI | 130 | 10.25 | 0.00 | 4.33 | 0.98 |
| P-98 | 69.32 | 400 | DCI | 130 | 9.69 | 0.00 | 5.56 | 2.19 |

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|---|---|---|---|---|---|---|---|---|
| P-99 | 85.47 | 250 | PVC | 150 | 9.02 | 0.85 | 3.74 | 0.006 |
| P-100 | 105.85 | 250 | PVC | 150 | -31.45 | 2.54 | 5.85 | 0.75 |
| P-101 | 80.65 | 250 | PVC | 150 | -4.25 | 1.34 | 4.24 | 5.14 |
| P-102 | 120.74 | 250 | PVC | 150 | -10.25 | 0.98 | 3.95 | 2.26 |
| P-103 | 156.89 | 250 | PVC | 150 | -12.45 | 1.19 | 4.45 | 0.85 |
| P-104 | 50.25 | 250 | PVC | 150 | -17.25 | 1.25 | 4.21 | 1.38 |
| P-105 | 80.49 | 250 | PVC | 150 | 13.14 | 0.45 | 4.05 | 0.79 |
| P-106 | 120.89 | 100 | PVC | 150 | 12.32 | 0.08 | 3.56 | 0.009 |
| P-107 | 109.75 | 100 | PVC | 150 | 14.36 | 1.26 | 1.14 | 1.54 |
| P-108 | 130.86 | 100 | PVC | 150 | 10.97 | 0.56 | 0.92 | 0.23 |
| P-109 | 85.65 | 150 | PVC | 150 | 12.71 | 0.73 | 1.63 | 1.56 |
| P-110 | 54.21 | 150 | PVC | 150 | 7.48 | 1.09 | 1.98 | 0.35 |
| P-111 | 100.96 | 150 | PVC | 150 | 0.15 | 0.82 | 0.47 | 0.87 |
| P-112 | 180.12 | 150 | PVC | 150 | 0.75 | 1.02 | 0.15 | 0.95 |
| P-113 | 100.35 | 150 | HDPE | 120 | 35.51 | 0.16 | 0.48 | 2.55 |
| P-114 | 85.21 | 150 | HDPE | 120 | 22.45 | 1.28 | 1.78 | 1.54 |
| P-115 | 97.25 | 150 | HDPE | 120 | 15.01 | 0.78 | 0.09 | 1.25 |
| P-116 | 75.48 | 150 | HDPE | 120 | 12.12 | 0.00 | 7.52 | 1.25 |
| P-117 | 85.12 | 150 | HDPE | 120 | 21.37 | 0.00 | 36.21 | 0.009 |
| P-118 | 50.65 | 250 | HDPE | 120 | 8.14 | 0.00 | 4.11 | 0.54 |
| P-119 | 56.87 | 250 | HDPE | 120 | 12.47 | 0.00 | 8.63 | 1.25 |
| P-120 | 95.2 | 250 | HDPE | 120 | 12.74 | 0.00 | 165.45 | 2.24 |
| P-121 | 80.12 | 250 | HDPE | 120 | -15.47 | 3.47 | 0.78 | 1.69 |
| P-122 | 100.19 | 100 | HDPE | 120 | 11.75 | 5.88 | 0.89 | 0.78 |
| P-123 | 120.75 | 100 | PVC | 150 | 15.74 | 1.45 | 1.45 | 1.41 |
| P-124 | 47 | 100 | PVC | 150 | 13.47 | 0.85 | 0.87 | 0.48 |
| P-125 | 0.85 | 100 | PVC | 150 | 15.74 | 0.63 | 0.48 | 1.02 |
| P-126 | 180.74 | 100 | PVC | 150 | 16.84 | 0.59 | 0.74 | 0.65 |
| P-127 | 65.25 | 100 | PVC | 150 | 16.05 | 0.95 | 287.6 | 10.06 |
| P-128 | 120.96 | 100 | PVC | 150 | 9.56 | 0.87 | 245.24 | 2.95 |
| P-129 | 85.41 | 100 | PVC | 150 | 15.51 | 0.89 | 124.54 | 1.83 |
| P-130 | 75.65 | 100 | PVC | 150 | 10.12 | 0.54 | 218.36 | 4.76 |
| P-131 | 100.45 | 100 | PVC | 150 | 11.75 | 0.86 | 45.05 | 1.75 |
| P-132 | 95.21 | 100 | PVC | 150 | -15.14 | 1.09 | 189.42 | 5.28 |
| P-133 | 150.98 | 100 | PVC | 150 | -24.01 | 0.78 | 0.03 | 0.85 |
| P-134 | 100.45 | 250 | PVC | 150 | -5.48 | 1.85 | 0.12 | 0.85 |
| P-135 | 150.25 | 250 | PVC | 150 | -41.12 | 0.09 | 1.07 | 0.00 |
| P-136 | 108.45 | 250 | PVC | 150 | 17.32 | 0.75 | 1.05 | 1.01 |
| P-137 | 85.14 | 250 | PVC | 150 | 18.12 | 0.00 | 0.78 | 0.98 |
| P-138 | 98.24 | 250 | PVC | 150 | 17.05 | 0.00 | 0.98 | 0.84 |
| P-139 | 150.48 | 250 | PVC | 150 | 3.54 | 0.00 | 0.09 | 1.05 |

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|---|---|---|---|---|---|---|---|---|
| P-140 | 80.45 | 250 | PVC | 150 | 0.24 | 0.00 | 0.14 | 1.78 |
| P-141 | 50.14 | 150 | PVC | 150 | 7.05 | 0.00 | 0.45 | 0.48 |
| P-142 | 89.54 | 150 | PVC | 150 | 5.12 | 0.00 | 1.48 | 1.98 |
| P-143 | 102.74 | 150 | PVC | 150 | 0.78 | 0.00 | 0.85 | 1.43 |
| P-144 | 80.65 | 150 | PVC | 150 | 0.85 | 0.24 | 0.65 | 0.78 |
| P-145 | 95.62 | 150 | PVC | 150 | -13.98 | 0.48 | 1.24 | 1.48 |
| P-146 | 65.25 | 150 | HDPE | 120 | -12.45 | 0.78 | 0.98 | 1.02 |
| P-147 | 120.48 | 150 | HDPE | 120 | -6.18 | 0.91 | 0.54 | 0.21 |
| P-148 | 89.21 | 150 | HDPE | 120 | -51.71 | 0.85 | 8.25 | 0.75 |
| P-149 | 85.21 | 150 | HDPE | 120 | -0.74 | 1.45 | 8.12 | 0.95 |
| P-150 | 100.65 | 400 | DCI | 130 | -21.63 | 1.24 | 1.58 | 0.22 |
| P-151 | 106.9 | 400 | DCI | 130 | 14.31 | 0.87 | 26.03 | 1.54 |
| P-152 | 100.47 | 400 | DCI | 130 | 11.21 | 0.46 | 0.32 | 0.00 |
| P-153 | 85.45 | 400 | DCI | 130 | 9.15 | 0.15 | 0.87 | 2.15 |
| P-154 | 56.25 | 400 | DCI | 130 | 4.09 | 0.28 | 0.78 | 0.81 |
| P-155 | 35.78 | 400 | DCI | 130 | 7.14 | 1.31 | 0.85 | 0.91 |
| P-156 | 59.45 | 100 | PVC | 150 | 13.14 | 0.89 | 0.49 | 0.88 |
| P-157 | 80.14 | 100 | PVC | 150 | 2.14 | 0.27 | 0.19 | 1.21 |
| P-158 | 10063 | 100 | PVC | 150 | 7.03 | 1.09 | 4.18 | 0.08 |
| P-159 | 120.35 | 100 | PVC | 150 | 8.16 | 0.84 | 4.65 | 1.04 |
| P-160 | 90.21 | 100 | PVC | 150 | 10.15 | 1.28 | 1.21 | 0.04 |
| P-161 | 60.25 | 100 | PVC | 150 | 0.95 | 0.47 | 0.18 | 0.19 |
| P-162 | 100.87 | 100 | PVC | 150 | 2.48 | 0.47 | 25.05 | 6.31 |
| P-163 | 150.89 | 100 | PVC | 150 | 0.78 | 0.85 | 71.05 | 4.01 |
| P-164 | 104.54 | 200 | PVC | 150 | 30.24 | 0.48 | 35.18 | 0.75 |
| P-165 | 150.23 | 200 | PVC | 150 | 12.15 | 0.67 | 0.21 | 0.007 |
| P-166 | 80.65 | 200 | PVC | 150 | 2.09 | 0.78 | 0.21 | 1.66 |
| P-167 | 75.45 | 200 | PVC | 150 | 14.41 | 1.25 | 2.59 | 1.98 |
| P-168 | 100.98 | 200 | PVC | 150 | 5.24 | 0.87 | 1.08 | 3.75 |
| P-169 | 100.54 | 200 | PVC | 150 | 11.03 | 0.98 | 3.18 | 1.54 |
| P-170 | 109.54 | 200 | PVC | 150 | 10.48 | 0.98 | 1.51 | 0.51 |
| P-171 | 110.78 | 200 | PVC | 150 | 15.52 | 1.28 | 6.23 | 0.82 |
| P-172 | 65.21 | 250 | PVC | 150 | 1.27 | 0.54 | 5.71 | 0.95 |
| P-173 | 105.23 | 250 | PVC | 150 | 7.74 | 0.15 | 6.05 | 0.87 |
| P-174 | 150.26 | 250 | PVC | 150 | 12.45 | 0.74 | 5.21 | 1.51 |
| P-175 | 80.56 | 250 | PVC | 150 | 16.41 | 0.91 | 0.74 | 5.21 |
| P-176 | 85.63 | 250 | PVC | 150 | 16.04 | 0.84 | 0.36 | 0.00 |
| P-177 | 156.24 | 250 | PVC | 150 | 11.05 | 0.81 | 0.98 | 4.73 |
| P-178 | 100.59 | 250 | PVC | 150 | 20.01 | 1.82 | 0.85 | 3.45 |
| P-179 | 80.63 | 250 | PVC | 150 | 15.05 | 0.85 | 0.09 | 0.00 |
| P-180 | 75.12 | 250 | PVC | 150 | 12.45 | 0.00 | 4.47 | 2.25 |

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|---|---|---|---|---|---|---|---|---|
| P-181 | 65.24 | 250 | PVC | 150 | 8.17 | 0.00 | 3.48 | 4.01 |
| P-182 | 100.63 | 250 | PVC | 150 | 20.57 | 0.00 | 2.97 | 2.78 |
| P-183 | 80.78 | 250 | PVC | 150 | 3.54 | 0.00 | 0.87 | 0.98 |
| P-184 | 89.53 | 250 | PVC | 150 | 15.13 | 0.00 | 0.48 | 2.65 |
| P-185 | 45.65 | 250 | HDPE | 120 | 15.47 | 0.00 | 1.48 | 1.89 |
| P-186 | 65.21 | 100 | HDPE | 120 | 10.54 | 0.00 | 1.06 | 0.28 |
| P-187 | 110.96 | 100 | HDPE | 120 | -5.54 | 8.52 | 0.65 | 1.39 |
| P-188 | 100.56 | 100 | HDPE | 120 | -41.37 | 10.16 | 2.94 | 1.08 |
| P-189 | 120.52 | 100 | HDPE | 120 | -0.83 | 0.49 | 2.46 | 0.87 |
| P-190 | 100.78 | 100 | HDPE | 120 | 10.08 | 0.58 | 0.42 | 0.71 |
| P-191 | 80.65 | 100 | HDPE | 120 | 5.71 | 0.09 | 7.65 | 0.94 |
| P-192 | 70.25 | 100 | HDPE | 120 | 1.48 | 0.87 | 9.25 | 0.42 |
| P-193 | 75.63 | 100 | HDPE | 120 | 3.57 | 7.02 | 0.87 | 0.51 |
| P-194 | 52.21 | 100 | HDPE | 120 | 3.08 | 38.36 | 0.48 | 2.82 |
| P-195 | 125.63 | 100 | HDPE | 120 | 0.76 | 1.09 | 0.51 | 0.97 |
| P-196 | 80.12 | 100 | HDPE | 120 | 6.38 | 0.85 | 0.74 | 1.08 |
| P-197 | 100.96 | 350 | PVC | 150 | 0.75 | 0.87 | 0.97 | 0.81 |
| P-198 | 145.24 | 350 | PVC | 150 | 11.27 | 0.85 | 1.23 | 0.94 |
| P-199 | 85.35 | 350 | PVC | 150 | 12.31 | 1.05 | 0.97 | 0.84 |
| P-200 | 56.25 | 350 | PVC | 150 | 13.45 | 0.86 | 0.78 | 1.27 |
| P-201 | 32.25 | 350 | PVC | 150 | 0.76 | 1.05 | 1.27 | 4.54 |
| P-202 | 30.58 | 350 | PVC | 150 | 10.29 | 0.84 | 0.96 | 2.65 |
| P-203 | 41.65 | 350 | PVC | 150 | 2.28 | 19.12 | 0.19 | 0.08 |
| P-204 | 85.12 | 150 | PVC | 150 | 0.95 | 12.02 | 0.01 | 1.54 |
| P-205 | 102.35 | 150 | PVC | 150 | 10.47 | 0.88 | 2.41 | 2.95 |
| P-206 | 105.26 | 150 | PVC | 150 | 11.21 | 1.58 | 1.79 | 3.28 |
| P-207 | 85.36 | 150 | PVC | 150 | 6.74 | 3.08 | 8.54 | 0.81 |
| P-208 | 45.12 | 150 | PVC | 150 | 0.49 | 0.49 | 1.38 | 0.99 |
| P-209 | 75.25 | 150 | PVC | 150 | 14.37 | 1.25 | 5.84 | 1.04 |
| P-210 | 85.15 | 150 | PVC | 150 | 19.47 | 1.25 | 0.58 | 1.49 |
| P-211 | 80.63 | 150 | PVC | 150 | 9.36 | 1.98 | 1.03 | 0.82 |
| P-212 | 84.65 | 150 | PVC | 150 | 15.64 | 1.52 | 0.75 | 0.67 |
| P-213 | 65.12 | 150 | PVC | 150 | 10.08 | 0.76 | 0.95 | 0.46 |
| P-214 | 58.26 | 100 | PVC | 150 | 8.28 | 2.41 | 0.98 | 1.57 |
| P-215 | 65.32 | 100 | PVC | 150 | 3.64 | 0.75 | 1.32 | 0.97 |
| P-216 | 65.12 | 100 | PVC | 150 | 6.25 | 0.53 | 0.47 | 1.87 |
| P-217 | 86.12 | 100 | PVC | 150 | 19.15 | 0.81 | 0.79 | 2.71 |
| P-218 | 105.26 | 100 | PVC | 150 | 12.65 | 1.08 | 0.02 | 0.44 |
| P-219 | 25.36 | 100 | PVC | 150 | 8.12 | 1.07 | 0.65 | 2.75 |
| P-220 | 52.63 | 100 | PVC | 150 | 11.45 | 0.51 | 2.81 | 0.65 |
| P-221 | 89.56 | 100 | PVC | 150 | -0.46 | 0.85 | 0.29 | 0.07 |

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|---|---|---|---|---|---|---|---|---|
| P-222 | 19.25 | 100 | PVC | 150 | -9.33 | 1.94 | 0.87 | 2.03 |
| P-223 | 36.21 | 100 | PVC | 150 | -12.07 | 0.84 | 0.25 | 0.76 |
| P-224 | 45.25 | 100 | PVC | 150 | -21.08 | 2.74 | 0.72 | 1.06 |
| P-225 | 48.25 | 100 | PVC | 150 | 10.28 | 25.27 | 0.28 | 1.81 |
| P-226 | 102.56 | 100 | PVC | 150 | 2.47 | 0.83 | 0.26 | 4.05 |
| P-227 | 105.26 | 100 | PVC | 150 | 3.25 | 1.85 | 1.06 | 0.55 |
| P-228 | 100.65 | 100 | PVC | 150 | 11.27 | 0.49 | 0.28 | 0.48 |
| P-229 | 16.5 | 100 | PVC | 150 | 7.26 | 1.24 | 0.65 | 0.98 |
| P-230 | 56.12 | 100 | PVC | 150 | 1.58 | 0.46 | 0.75 | 0.19 |
| P-231 | 26.65 | 250 | PVC | 150 | 0.97 | 0.86 | 3.56 | 2.18 |
| P-232 | 89.75 | 250 | PVC | 150 | 9.52 | 0.94 | 5.95 | 2.48 |
| P-233 | 100.58 | 250 | PVC | 150 | 8.51 | 1.59 | 5.18 | 0.92 |
| P-234 | 45.31 | 250 | PVC | 150 | -0.51 | 0.81 | 4.62 | 2.46 |
| P-235 | 63.25 | 250 | PVC | 150 | 3.21 | 1.06 | 4.57 | 5.06 |
| P-236 | 45.12 | 250 | PVC | 150 | 2.17 | 0.48 | 4.66 | 5.08 |
| P-237 | 56.25 | 250 | PVC | 150 | 15.49 | 0.25 | 4.74 | 0.94 |
| P-238 | 80.25 | 250 | PVC | 150 | 6.47 | 0.48 | 4.29 | 0.62 |
| P-239 | 105.65 | 80 | HDPE | 120 | 0.98 | 0.06 | 4.74 | 3.64 |
| P-240 | 65.23 | 80 | HDPE | 120 | 0.46 | 0.00 | 5.07 | 2.05 |
| P-241 | 100.26 | 80 | HDPE | 120 | 1.05 | 0.00 | 4.51 | 1.25 |
| P-242 | 105.56 | 80 | HDPE | 120 | 16.14 | 0.41 | 4.15 | 8.57 |
| P-243 | 120.36 | 80 | HDPE | 120 | 14.35 | 0.09 | 4.18 | 3.15 |
| P-244 | 25.65 | 80 | HDPE | 120 | 3.08 | 0.34 | 5.56 | 4.48 |
| P-245 | 65.25 | 80 | HDPE | 120 | 1.24 | 2.04 | 4.35 | 2.56 |
| P-246 | 109.36 | 80 | HDPE | 120 | 1.28 | 4.01 | 3.49 | 0.68 |
| P-247 | 130.89 | 80 | HDPE | 120 | 4.05 | 1.78 | 3.19 | 1.25 |
| P-248 | 65.89 | 80 | HDPE | 120 | 0.48 | 0.71 | 1.59 | 2.18 |
| P-249 | 87.45 | 80 | HDPE | 120 | 4.12 | 0.95 | 0.17 | 0.09 |
| P-250 | 109.25 | 80 | HDPE | 120 | 16.01 | 0.98 | 0.47 | 1.29 |
| P-251 | 100.96 | 80 | HDPE | 120 | 0.74 | 1.08 | 0.73 | 0.47 |
| P-252 | 98.25 | 80 | HDPE | 120 | 1.27 | 0.81 | 0.94 | 0.34 |
| P-253 | 65.25 | 80 | HDPE | 120 | 1.82 | 1.19 | 0.73 | 1.38 |
| P-254 | 65.36 | 80 | HDPE | 120 | 13.48 | 1.56 | 0.98 | 0.91 |
| P-255 | 80.12 | 150 | HDPE | 120 | 14.05 | 1.49 | 0.53 | 0.86 |
| P-256 | 45.21 | 150 | HDPE | 120 | 1.49 | 0.73 | 0.87 | 1.56 |
| P-257 | 98.25 | 150 | HDPE | 120 | 9.12 | 1.06 | 0.97 | 1.28 |
| P-258 | 65.25 | 150 | HDPE | 120 | 17.63 | 1.02 | 0.72 | 0.95 |
| P-259 | 108.75 | 150 | HDPE | 120 | 24.15 | 0.48 | 0.73 | 0.82 |
| P-260 | 120.39 | 150 | HDPE | 120 | 7.18 | 1.04 | 1.74 | 3.09 |
| P-261 | 105.65 | 150 | HDPE | 120 | 1.87 | 0.72 | 0.91 | 1.81 |
| P-262 | 25.65 | 150 | HDPE | 120 | 0.87 | 0.49 | 0.98 | 1.93 |

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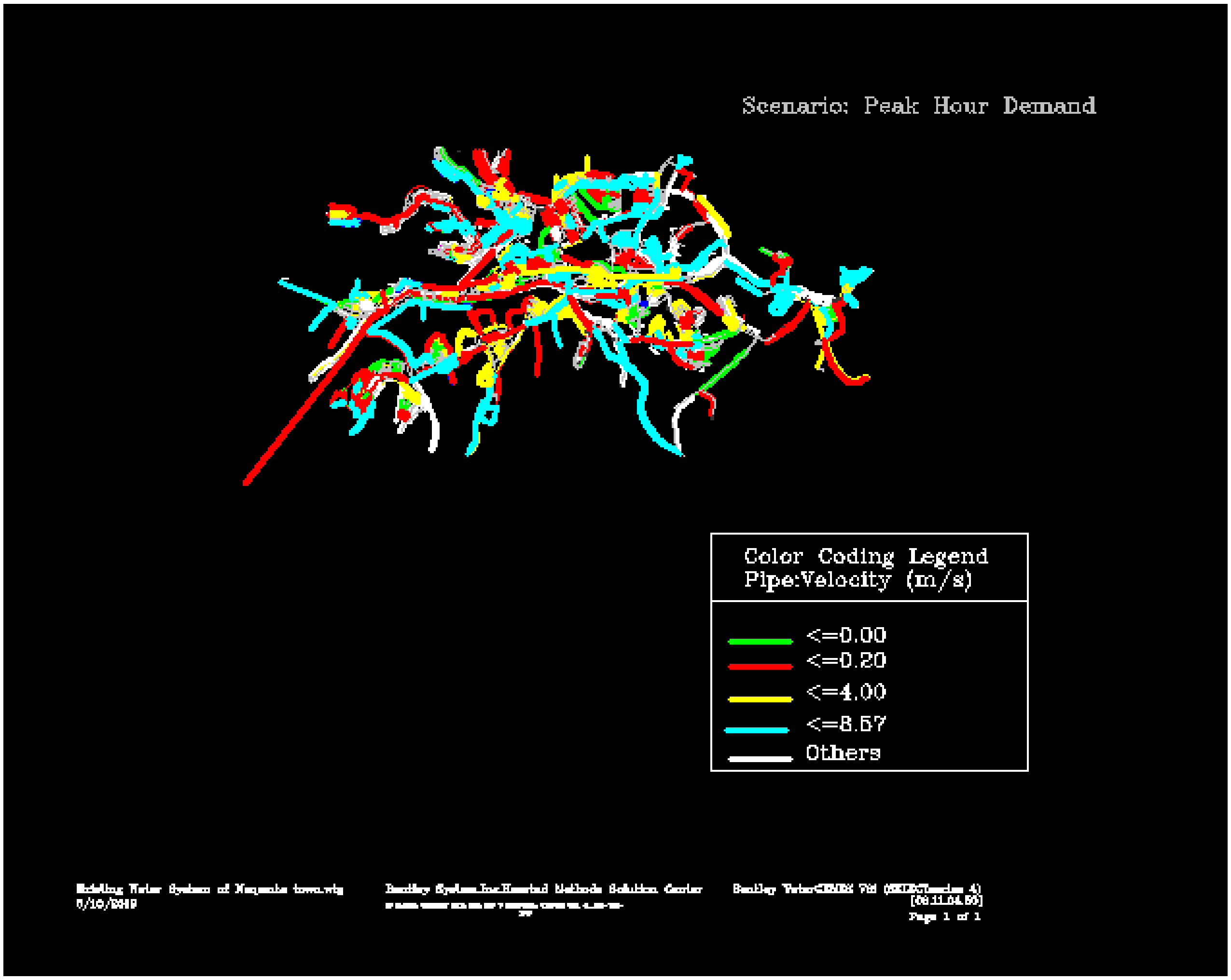
|---|---|---|---|---|---|---|---|---|
| P-263 | 107.26 | 150 | HDPE | 120 | 1.85 | 1.16 | 1.02 | 0.67 |
| P-264 | 150.32 | 150 | HDPE | 120 | 0.74 | 0.73 | 1.68 | 0.28 |
| P-265 | 26.53 | 150 | HDPE | 120 | 0.97 | 0.97 | 1.32 | 0.49 |
| P-266 | 85.14 | 150 | HDPE | 120 | 0.97 | 0.49 | 0.97 | 1.75 |
| P-267 | 95.25 | 100 | HDPE | 120 | 1.08 | 1.28 | 1.07 | 0.93 |
| P-268 | 36.12 | 100 | HDPE | 120 | 12.07 | 1.05 | 1.04 | 1.59 |
| P-269 | 48.15 | 100 | HDPE | 120 | 28.12 | 15.51 | 1.04 | 0.82 |
| P-270 | 65.27 | 100 | HDPE | 120 | 54.02 | 6.05 | 1.42 | 0.64 |
| P-271 | 104.16 | 100 | HDPE | 120 | 11.05 | 29.13 | 0.05 | 6.15 |
| P-272 | 75.26 | 100 | HDPE | 120 | 13.48 | 16.06 | 0.08 | 4.24 |
| P-273 | 100.29 | 100 | HDPE | 120 | 2.85 | 1.68 | 0.08 | 5.29 |
| P-274 | 103.45 | 200 | PVC | 150 | 10.68 | 0.18 | 0.85 | 5.48 |
| P-275 | 85.16 | 200 | PVC | 150 | 6.33 | 0.73 | 0.58 | 0.61 |
| P-276 | 89.14 | 200 | PVC | 150 | 50.01 | 0.79 | 0.19 | 0.08 |
| P-277 | 14.98 | 200 | PVC | 150 | 19.08 | 1.47 | 29.18 | 0.00 |
| P-278 | 102.8 | 200 | PVC | 150 | -0.45 | 2.09 | 169.43 | 0.75 |
| P-279 | 100.49 | 200 | PVC | 150 | -0.19 | 30.18 | 189.04 | 2.75 |
| P-280 | 36.87 | 200 | PVC | 150 | -4.01 | 0.95 | 0.17 | 0.48 |
| P-281 | 108.26 | 200 | PVC | 150 | -0.64 | 0.27 | 182.45 | 5.06 |
| P-282 | 80.15 | 200 | PVC | 150 | 6.08 | 1.06 | 60.25 | 0.47 |
| P-283 | 75.29 | 200 | PVC | 150 | 9.48 | 0.84 | 0.18 | 0.09 |
| P-284 | 130.89 | 500 | DCI | 130 | 16.63 | 0.28 | 0.76 | 0.82 |
| P-285 | 25.65 | 500 | DCI | 130 | 14.37 | 1.45 | 0.96 | 0.28 |
| P-286 | 158.26 | 500 | DCI | 130 | 12.52 | 0.83 | 65.18 | 4.65 |
| P-287 | 148.13 | 500 | DCI | 130 | 15.61 | 1.06 | 10.19 | 4.78 |
| P-288 | 100.25 | 500 | DCI | 130 | 1.03 | 0.96 | 2.58 | 0.71 |
| P-289 | 50.32 | 500 | DCI | 130 | 4.34 | 0.85 | 0.15 | 0.35 |
| P-290 | 85.25 | 500 | DCI | 130 | 16.06 | 6.01 | 0.65 | 0.29 |
| P-291 | 89.15 | 500 | DCI | 130 | 1.64 | 0.96 | 0.64 | 1.67 |
| P-292 | 100.89 | 80 | HDPE | 120 | 15.96 | 0.92 | 1.07 | 1.24 |
| P-293 | 80.96 | 80 | HDPE | 120 | 1.68 | 0.00 | 1.63 | 4.61 |
| P-294 | 65.25 | 80 | HDPE | 120 | 0.65 | 1.74 | 1.49 | 1.09 |
| P-295 | 120.58 | 80 | HDPE | 120 | 0.45 | 0.00 | 2.05 | 2.01 |
| P-296 | 89.26 | 80 | HDPE | 120 | 3.52 | 0.00 | 2.08 | 6.57 |
| P-297 | 150.85 | 80 | HDPE | 120 | 0.95 | 0.00 | 0.49 | 0.27 |
| P-298 | 56.26 | 200 | PVC | 150 | 0.82 | 0.00 | 7.67 | 0.18 |
| P-299 | 98.65 | 200 | PVC | 150 | 0.75 | 0.00 | 0.14 | 0.61 |
| P-300 | 47.15 | 200 | PVC | 150 | 0.09 | 0.49 | 6.31 | 1.35 |
| P-301 | 84.15 | 200 | PVC | 150 | 9.24 | 0.84 | 2.61 | 1.08 |
| P-302 | 85.14 | 200 | PVC | 150 | -2.15 | 0.52 | 2.64 | 1.32 |
| P-303 | 89.26 | 200 | PVC | 150 | -25.05 | 0.67 | 2.31 | 0.00 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| P-304 | 67.15 | 200 | PVC | 150 | 17.43 | 0.84 | 0.27 | 0.93 |
| P-305 | 60.25 | 200 | PVC | 150 | 15.07 | 0.91 | 0.61 | 0.38 |
| P-306 | 105.69 | 200 | PVC | 150 | 8.07 | 0.63 | 1.25 | 0.78 |
| P-307 | 100.25 | 200 | PVC | 150 | 10.09 | 0.28 | 1.45 | 0.94 |
| P-308 | 56.36 | 200 | PVC | 150 | 12.48 | 0.67 | 4.67 | 2.48 |
| P-309 | 150.25 | 200 | PVC | 150 | 8.15 | 0.74 | 0.65 | 0.27 |
| P-310 | 69.32 | 150 | PVC | 150 | 10.64 | 0.81 | 0.18 | 0.06 |
| P-311 | 80.12 | 150 | PVC | 150 | 8.54 | 0.76 | 2.18 | 0.48 |
| P-312 | 75.15 | 150 | PVC | 150 | 0.55 | 0.91 | 0.62 | 0.38 |
| P-313 | 98.13 | 150 | PVC | 150 | 2.67 | 0.95 | 0.57 | 0.85 |
| P-314 | 90.25 | 150 | HDPE | 120 | 3.05 | 0.86 | 1.65 | 0.59 |
| P-315 | 65.26 | 150 | HDPE | 120 | 45.05 | 0.43 | 0.93 | 0.74 |
| P-316 | 120.25 | 150 | HDPE | 120 | 0.47 | 0.82 | 5.34 | 0.57 |
| P-317 | 102.65 | 150 | HDPE | 120 | -0.54 | 0.51 | 3.18 | 0.61 |
| P-318 | 56.15 | 150 | HDPE | 120 | -2.65 | 0.34 | 0.48 | 0.82 |
| P-319 | 96.36 | 150 | HDPE | 120 | -62.08 | 0.87 | 0.37 | 0.94 |
| P-320 | 87.12 | 150 | HDPE | 120 | -3.15 | 0.97 | 0.48 | 0.01 |
| P-321 | 100.56 | 150 | HDPE | 120 | 10.19 | 3.28 | 0.64 | 0.59 |
| P-322 | 96.26 | 150 | HDPE | 120 | 13.24 | 40.61 | 0.28 | 0.63 |
| P-323 | 49.87 | 150 | HDPE | 120 | 11.27 | 3.05 | 1.81 | 3.12 |
| P-324 | 90.36 | 150 | HDPE | 120 | 0.75 | 0.00 | 0.93 | 0.45 |
| P-325 | 110.89 | 150 | HDPE | 120 | 5.04 | 0.00 | 6.08 | 5.14 |
| P-326 | 80.45 | 150 | HDPE | 120 | 6.08 | 1.29 | 4.52 | 1.28 |
| P-327 | 69.32 | 150 | HDPE | 120 | 10.27 | 7.15 | 4.26 | 0.96 |
| P-328 | 78.52 | 150 | HDPE | 120 | 15.01 | 0.45 | 3.18 | 2.58 |

**Annexes H6:** Velocity Map of Links for Peak Hour Demand Scenario, EPS Analysis




## Annexes-H7: Nodes EPS analysis result at peak hour demand

| Label | Elevation (m) | Demand (Calculated) (l/s) | Calculated Hydraulic Grade (m) | Pressure (m H2O) | Base Flow (l/s) |
|---|---|---|---|---|---|
| J-1 | 1,900.00 | 0.00 | 1,279.76 | 65.6 | 0.1 |
| J-2 | 2,140.00 | 0.00 | 1,228.26 | 29.21 | 0.2 |
| J-3 | 2,000.00 | 0.01 | 1,949.09 | 56.01 | 0.18 |
| J-4 | 2,148.25 | 0.06 | 2,379.36 | 0.58 | 0.00 |
| J-5 | 1,995.00 | 0.02 | 1,798.43 | 57.23 | 0.67 |
| J-6 | 2,111.25 | 0.18 | 2,227.06 | 38.01 | 0.51 |
| J-7 | 1,890.00 | 0.57 | 1,274.74 | 58.52 | 0.18 |
| J-8 | 1,900.00 | 0.85 | 1,264.75 | 86.58 | 0.12 |
| J-9 | 2,100.00 | 0.00 | 2,120.96 | 86.22 | 0.48 |
| J-10 | 1,900.00 | 0.75 | 1,962.47 | 10.65 | 0.95 |
| J-11 | 1,885.00 | 0.00 | 2,122.11 | 3.65 | 0.48 |
| J-12 | 2,000.00 | 0.00 | 1,882.01 | 65.91 | 0.35 |

| | | | | | |
|---|---|---|---|---|---|
| J-13 | 1,900.00 | 0.00 | 1,782.01 | 45.85 | 0.00 |
| J-14 | 2,000.00 | 0.65 | 1,781.39 | 71.49 | 0.34 |
| J-15 | 2,100.00 | 0.54 | 2,147.35 | 87.15 | 0.16 |
| J-16 | 2,100.00 | 0.00 | 1,812.15 | 15.24 | 0.28 |
| J-17 | 1,900.75 | 0.14 | 1,996.39 | 75.24 | 0.16 |
| J-18 | 2,115.00 | 0.15 | 1,887.49 | 57.14 | 0.98 |
| J-19 | 1,995.00 | 0.24 | 2,199.15 | 329.24 | 0.00 |
| J-20 | 2,000.00 | 0.15 | 2,212.99 | 65.04 | 0.51 |
| J-21 | 1,885.00 | 0.00 | 1,289.58 | 47.15 | 0.27 |
| J-22 | 1,950.00 | 0.00 | 2,221.14 | 25.18 | 0.00 |
| J-23 | 1,800.00 | 0.00 | 2,125.98 | 35.14 | 0.18 |
| J-24 | 1,900.00 | 0.17 | 1,619.04 | 45.14 | 0.00 |
| J-25 | 2,000.00 | 0.01 | 1,970.08 | 48.15 | 0.18 |
| J-26 | 2,000.00 | 0.45 | 2,191.27 | 87.04 | 0.14 |
| J-27 | 1,900.00 | 0.14 | 1,298.27 | 45.06 | 0.00 |
| J-28 | 1,900.00 | 0.54 | 2,169.64 | 85.12 | 0.18 |
| J-29 | 2,110.00 | 0.15 | 2,076.15 | 75.00 | 0.19 |
| J-30 | 1,900.00 | 0.00 | 2,185.11 | 15.18 | 0.08 |
| J-31 | 1,900.00 | 0.14 | 1,987.18 | 45.12 | 0.16 |
| J-32 | 2,040.00 | 0.18 | 2,061.22 | 0.78 | 0.00 |
| J-33 | 1,900.00 | 0.25 | 2,215.14 | 8.65 | 0.38 |
| J-34 | 1,895.00 | 0.18 | 1,897.48 | 97.48 | 0.25 |
| J-35 | 2,100.00 | 0.00 | 1,918.14 | 19.84 | 0.01 |
| J-36 | 2,000.00 | 0.00 | 1,981.18 | 96.15 | 0.09 |
| J-37 | 2,000.00 | 0.18 | 1,987.18 | 58.15 | 0.24 |
| J-38 | 1,800.00 | 0.81 | 2,073.12 | 55.15 | 0.00 |
| J-39 | 1,990.00 | 0.13 | 1,946.23 | 15.22 | 0.56 |
| J-40 | 1,800.00 | 0.00 | 1,985.00 | 65.15 | 0.15 |
| J-41 | 1,750.00 | 0.54 | 2,121.05 | 52.10 | 0.18 |
| J-42 | 1,995.00 | 0.14 | 1,954.15 | 64.52 | 0.24 |
| J-43 | 2,000.00 | 0.14 | 1,984.15 | 38.01 | 0.00 |
| J-44 | 1,700.00 | 0.48 | 1,964.83 | 78.15 | 0.00 |
| J-45 | 1,750.00 | 0.00 | 1,984.48 | 48.15 | 0.48 |
| J-46 | 2,100.00 | 0.65 | 1,990.15 | 78.14 | 0.00 |
| J-47 | 2,000.00 | 0.00 | 1,985.45 | 25.14 | 0.18 |
| J-48 | 2,100.00 | 0.45 | 1,978.24 | 78.00 | 0.15 |
| J-49 | 2,000.00 | 0.24 | 1,925.48 | 28.45 | 0.00 |
| J-50 | 2,000.00 | 0.19 | 1,987.17 | 98.15 | 0.13 |
| J-51 | 2,100.00 | 0.00 | 2061.11 | 10.48 | 0.00 |
| J-52 | 2,100.00 | 0.00 | 2,128.13 | 48.02 | 0.00 |
| J-53 | 1,900.00 | 0.04 | 1,913.00 | 18.15 | 0.04 |

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|---|---|---|---|---|---|
| J-54 | 2,000.00 | 0.14 | 1,958.00 | 68.14 | 0.48 |
| J-55 | 2,000.00 | 0.09 | 1,872.14 | 10.15 | 0.00 |
| J-56 | 2,000.00 | 0.09 | 2,138.33 | 30.02 | 0.01 |
| J-57 | 2,120.00 | 0.00 | 1,954.54 | 45.15 | 0.45 |
| J-58 | 2,000.00 | 0.00 | 1,960.45 | 56.012 | 0.52 |
| J-59 | 2,000.00 | 0.48 | 1,994.65 | 89.14 | 0.58 |
| J-60 | 2,105.00 | 0.09 | 2,259.00 | 9.00 | 0.00 |
| J-61 | 1,925.00 | 0.00 | 2,176.47 | 48.14 | 0.19 |
| J-62 | 2,000.00 | 0.12 | 1,902.14 | 3.14 | 0.18 |
| J-63 | 2,040.00 | 0.58 | 1,918.47 | 200.47 | 0.19 |
| J-64 | 2,000.00 | 0.00 | 1,952.15 | 143.71 | 0.24 |
| J-65 | 2,100.00 | 0.00 | 2,213.28 | 89.01 | 0.05 |
| J-66 | 1,885.00 | 0.08 | 1,980.56 | 41.15 | 0.07 |
| J-67 | 2,130.00 | 0.07 | 2,134.28 | 12.05 | 0.06 |
| J-68 | 2,130.00 | 0.09 | 2,180.00 | 10.48 | 0.08 |
| J-69 | 2,000.00 | 0.85 | 1,920.25 | 65.11 | 0.95 |
| J-70 | 2,100.00 | 0.19 | 1,948.14 | 12.18 | 0.64 |
| J-71 | 1,900.00 | 0.00 | 2,151.53 | 23.14 | 0.25 |
| J-72 | 2,100.00 | 0.00 | 1,992.29 | 40.54 | 0.29 |
| J-73 | 2,130.00 | 0.15 | 1,892.56 | 65.14 | 0.45 |
| J-74 | 2,000.00 | 0.04 | 2,130.32 | 75.01 | 0.15 |
| J-75 | 2,000.00 | 0.17 | 2,124.07 | 72.25 | 0.00 |
| J-76 | 1,750.00 | 0.48 | 1,965.53 | 24.41 | 0.37 |
| J-77 | 1,890.00 | 0.49 | 1,997.24 | 75.08 | 0.29 |
| J-78 | 1,700.00 | 1.25 | 1,897.04 | 52.24 | 0.29 |
| J-79 | 1,990.00 | 0.00 | 1,948.43 | 48.05 | 0.48 |
| J-80 | 2,135.00 | 0.00 | 1,986.26 | 96.18 | 0.43 |
| J-81 | 1,950.00 | 0.29 | 2,161.18 | 62.06 | 0.28 |
| J-82 | 1,700.00 | 0.00 | 2,176.48 | 52.35 | 0.05 |
| J-83 | 2,000.00 | 0.42 | 1,948.19 | 150.02 | 0.52 |
| J-84 | 2,010.00 | 0.09 | 2,054.72 | 35.28 | 0.04 |
| J-85 | 2,000.00 | 0.15 | 2,100.49 | 0.09 | 0.15 |
| J-86 | 2,000.00 | 0.28 | 1,989.61 | 89.12 | 0.23 |
| J-87 | 2,100.00 | 1.06 | 2,231.45 | 2.18 | 0.01 |
| J-88 | 2,000.00 | 0.05 | 2,052.43 | 42.34 | 0.04 |
| J-89 | 2,100.00 | 0.15 | 2,108.19 | 125.67 | 0.03 |
| J-90 | 2,000.00 | 0.18 | 1,983.08 | 95.15 | 0.25 |
| J-91 | 1,750.00 | 0.14 | 1,987.49 | 60.18 | 0.16 |
| J-92 | 1,700.00 | 0.00 | 1,987.40 | 37.15 | 0.08 |
| J-93 | 1,900.00 | 0.00 | 1,988.31 | 48.14 | 0.19 |
| J-94 | 1,990.00 | 0.15 | 1,967.54 | 87.05 | 0.00 |

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|---|---|---|---|---|---|
| J-95 | 2,000.00 | 0.08 | 2,027.05 | 65.09 | 0.27 |
| J-96 | 2,000.00 | 0.17 | 2,108.04 | 61.48 | 0.13 |
| J-97 | 1,900.00 | 0.07 | 2,004.65 | 10.14 | 0.06 |
| J-98 | 2,115.00 | 0.14 | 1,953.46 | 51.44 | 0.16 |
| J-99 | 2,000.00 | 0.00 | 1,988.17 | 45.46 | 0.28 |
| J-100 | 2,100.00 | 0.00 | 1,987.14 | 47.04 | 0.02 |
| J-101 | 2,100.00 | 0.00 | 2,046.18 | 36.14 | 0.05 |
| J-102 | 1,900.00 | 0.00 | 1,946.60 | 38.41 | 0.04 |
| J-103 | 2,100.00 | 0.41 | 2,034.67 | 42.19 | 0.15 |
| J-104 | 2,100.00 | 0.47 | 2,078.12 | -20.47 | 0.07 |
| J-105 | 1,885.00 | 0.12 | 2,098.64 | 18.32 | 0.02 |
| J-106 | 1,900.00 | 0.15 | 1,903.57 | -44.54 | 0.02 |
| J-107 | 2,115.25 | 0.02 | 2,026.41 | -86.23 | 0.02 |
| J-108 | 1,700.00 | 0.08 | 1,950.14 | 25.07 | 0.00 |
| J-109 | 2,120.00 | 0.14 | 2,080.17 | 15.91 | 0.12 |
| J-110 | 1,900.00 | 0.52 | 1,922.28 | 58.15 | 0.05 |
| J-111 | 1,900.00 | 0.14 | 1,901.10 | 41.18 | 0.01 |
| J-112 | 2,100.00 | 0.05 | 1,901.49 | 21.47 | 0.00 |
| J-113 | 1,800.00 | 0.00 | 1,948.77 | 18.67 | 0.04 |
| J-114 | 1,750.00 | 0.00 | 1,908.53 | 37.18 | 0.25 |
| J-115 | 1,900.00 | 0.24 | 1,978.30 | 52.24 | 0.17 |
| J-116 | 1,800.00 | 0.45 | 1,981.29 | 421.48 | 0.15 |
| J-117 | 1,800.00 | 0.09 | 1,846.91 | 12.05 | 0.25 |
| J-118 | 2,120.00 | 0.14 | 2,104.37 | 0.15 | 0.78 |
| J-119 | 1,950.00 | 0.07 | 1,985.45 | 48.07 | 0.59 |
| J-120 | 1,928.00 | 0.08 | 1,902.82 | 75.07 | 0.26 |
| J-121 | 2,000.00 | 0.17 | 2,101.49 | 160.53 | 0.25 |
| J-122 | 2,100.00 | 0.14 | 2,017.16 | 27.08 | 0.30 |
| J-123 | 2,000.00 | 6.01 | 2,106.24 | 22.04 | 5.01 |
| J-124 | 2,000.00 | 0.14 | 2,080.17 | 40.39 | 0.15 |
| J-125 | 2,000.00 | 0.25 | 2,022.16 | 45.09 | 0.14 |
| J-126 | 2,115.00 | 0.48 | 2,104.00 | 41.06 | 0.00 |
| J-127 | 2,000.00 | 0.00 | 2,049.08 | 24.03 | 0.19 |
| J-128 | 1,900.00 | 0.00 | 1,907.52 | 72.32 | 0.21 |
| J-129 | 1,900.00 | 0.00 | 1,9509.57 | 67.16 | 0.29 |
| J-130 | 2,120.00 | 0.00 | 2,007.15 | 95.44 | 0.14 |
| J-131 | 1,800.00 | 0.18 | 1,958.07 | 34.06 | 0.12 |
| J-132 | 2,000.00 | 0.11 | 2,069.02 | 10.54 | 0.10 |
| J-133 | 1,985.00 | 0.15 | 1,909.25 | 47.15 | 0.25 |
| J-134 | 1,900.00 | 0.65 | 1,921.40 | 68.15 | 0.62 |
| J-135 | 2,000.00 | 0.25 | 2,091.39 | 48.51 | 0.14 |

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|---|---|---|---|---|---|
| J-136 | 2,110.00 | 0.07 | 2,049.05 | 58.27 | 0.05 |
| J-137 | 2,000.00 | 0.12 | 2,019.08 | 29.48 | 0.16 |
| J-138 | 1,800.00 | 0.00 | 1,890.64 | 341.16 | 0.14 |
| J-139 | 1,900.00 | 0.00 | 1,932.40 | 47.13 | 0.02 |
| J-140 | 2,121.00 | 0.00 | 2,104.93 | 31.21 | 0.05 |
| J-141 | 2,000.00 | 0.00 | 2,090.61 | .13.04 | 0.08 |
| J-142 | 2,125.00 | 0.42 | 2,105.14 | 261.18 | 0.18 |
| J-143 | 2,115.00 | 0.05 | 2,050.43 | -60.37 | 0.02 |
| J-144 | 2,115.00 | 0.18 | 2,059.48 | -15.66 | 0.14 |
| J-145 | 2,100.00 | 0.03 | 2,081.73 | -205.17 | 0.18 |
| J-146 | 2,100.00 | 0.15 | 2,050.17 | -0.06 | 0.18 |
| J-147 | 1,990.00 | 0.05 | 1,932.18 | -2.14 | 0.08 |
| J-148 | 1,900.00 | 0.16 | 1,958.12 | 0.48 | 0.13 |
| J-149 | 1,870.00 | 0.14 | 1,807.49 | 15.18 | 0.93 |
| J-150 | 1,900.00 | 0.19 | 1,927.92 | 67.24 | 0.18 |
| J-151 | 1,900.00 | 0.08 | 1915.41 | 225.17 | 0.00 |
| J-152 | 2,100.00 | 0.08 | 2,069.14 | 45.16 | 0.21 |
| J-153 | 2,115.00 | 0.14 | 2,052.83 | 16.72 | 0.18 |
| J-154 | 1,885.00 | 0.15 | 1,812.61 | 314.15 | 0.13 |
| J-155 | 2,000.00 | 0.02 | 2,031.81 | 57.15 | 0.16 |
| J-156 | 1,995.00 | 0.14 | 1,940.10 | 65.37 | 0.02 |
| J-157 | 2,150.00 | 0.15 | 2,063.17 | 367.25 | 0.14 |
| J-158 | 2,000.00 | 0.73 | 2,041.63 | 14.73 | 0.06 |
| J-159 | 1,980.00 | 0.18 | 1,969.65 | 59.07 | 0.17 |
| J-160 | 1,800.00 | 0.00 | 1,814.00 | 49.46 | 0.09 |
| J-161 | 1,800.00 | 0.00 | 1,850.19 | 223.05 | 0.32 |
| J-162 | 2,000.00 | 0.00 | 2,134.24 | 102.55 | 0.19 |
| J-163 | 2,140.00 | 0.00 | 2,124.46 | 47.14 | 0.18 |
| J-164 | 1,995.00 | 0.23 | 1,907.94 | 51.29 | 0.01 |
| J-165 | 1,995.00 | 0.19 | 1,959.41 | -45.25 | 0.48 |
| J-166 | 2,000.00 | 0.08 | 2,108.76 | -49.62 | 0.15 |
| J-167 | 1,900.00 | 0.14 | 1,903.12 | -22.9 | 0.19 |
| J-168 | 2,100.00 | 0.15 | 2,105.24 | -0.69 | 0.14 |
| J-169 | 2,000.00 | 0.19 | 2,105.60 | 208.39 | 0.02 |
| J-170 | 2,114.00 | 0.03 | 2,010.14 | 129.45 | 0.18 |
| J-171 | 2,000.00 | 0.09 | 2,011.48 | 12.64 | 0.84 |
| J-172 | 2,115.00 | 0.19 | 2,107.41 | 40.08 | 0.08 |
| J-173 | 2,110.00 | 0.14 | 2,061.77 | 61.04 | 0.14 |
| J-174 | 2,000.00 | 0.13 | 2,060.45 | 43.07 | 0.18 |
| J-175 | 2,000.00 | 0.34 | 2,009.19 | -209.06 | 0.25 |
| J-176 | 1,900.00 | 0.08 | 1,904.50 | 95.14 | 0.08 |

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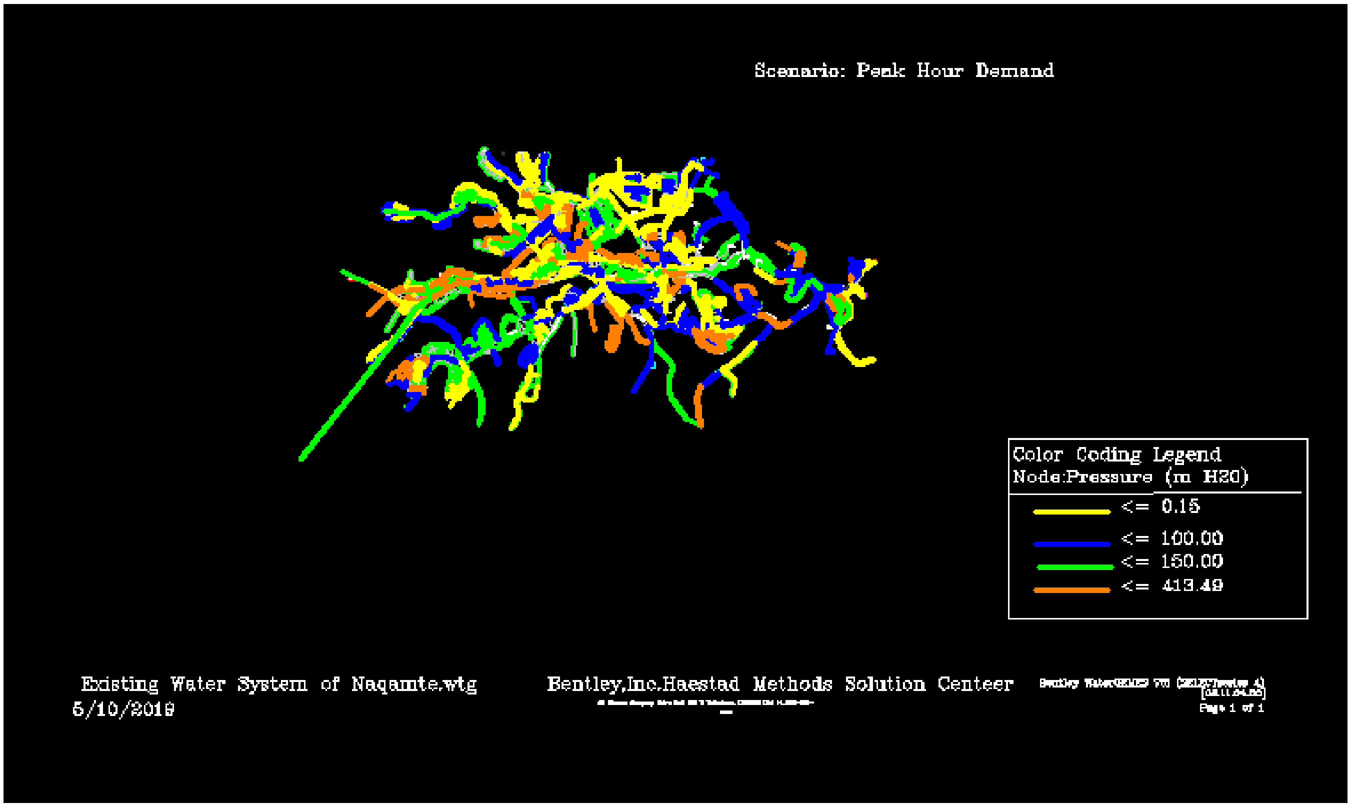
|---|---|---|---|---|---|
| J-177 | 2,000.00 | 0.15 | 2,012.20 | 121.07 | 0.08 |
| J-178 | 1,900.00 | 0.19 | 1,908.48 | 59.02 | 0.00 |
| J-179 | 2,000.00 | 0.09 | 2,068.73 | 10.81 | 0.00 |
| J-180 | 2,110.00 | 0.48 | 2,104.14 | 210.18 | 0.59 |
| J-181 | 2,100.00 | 0.18 | 2,004.43 | 159.12 | 0.08 |
| J-182 | 2,115.00 | 0.00 | 2,007.01 | 98.79 | 0.05 |
| J-183 | 1,995.00 | 0.00 | 1,953.15 | 52.11 | 0.08 |
| J-184 | 2,000.00 | 0.00 | 2,001.21 | 201.7 | 0.25 |
| J-185 | 1,998.25 | 0.00 | 1,991.74 | 357.34 | 0.54 |
| J-186 | 2,000.00 | 0.00 | 2,097.15 | 125.01 | 0.05 |
| J-187 | 1,900.00 | 0.08 | 1,920.70 | 145.12 | 0.16 |
| J-188 | 2,110.00 | 0.14 | 2,040.41 | 78.50 | 0.25 |
| J-189 | 2,100.00 | 0.19 | 2,068.04 | 157.15 | 0.35 |
| J-190 | 2,000.00 | 0.35 | 2,109.93 | 204.45 | 0.08 |
| J-191 | 2,000.00 | 0.89 | 2,005.48 | 109.32 | 0.17 |
| J-192 | 1,890.00 | 0.06 | 2,101.18 | 45.08 | 0.00 |
| J-193 | 1,995.00 | 0.18 | 2,007.55 | 428.85 | 0.19 |
| J-194 | 1,995.00 | 0.18 | 1,914.06 | 65.03 | 0.08 |
| J-195 | 2,000.00 | 0.15 | 2,069.15 | 219.06 | 0.58 |
| J-196 | 1,900.00 | 0.09 | 1,903.85 | 10.07 | 0.14 |
| J-197 | 2,100.00 | 0.23 | 2,128.04 | 6.41 | 0.08 |
| J-198 | 1,750.00 | 0.14 | 1,705.53 | 10.19 | 0.19 |
| J-199 | 2,000.00 | 0.09 | 2,109.69 | 109.24 | 0.02 |
| J-200 | 1,900.00 | 0.09 | 2,100.18 | 106.49 | 0.02 |
| J-201 | 1,800.00 | 0.09 | 1,840.28 | 51.72 | 0.02 |
| J-202 | 1,750.00 | 0.09 | 1,790.20 | 0.48 | 0.02 |
| J-203 | 2,000.00 | 0.09 | 2,006.42 | 109.45 | 0.02 |
| J-204 | 1,900.00 | 0.09 | 1,863.99 | 40.18 | 0.02 |
| J-205 | 2,150.00 | 0.18 | 2,119.77 | 257.18 | 0.25 |
| J-206 | 2,115.00 | 0.06 | 2,092.73 | 163.42 | 0.08 |
| J-207 | 2,100.00 | 0.14 | 2,105.09 | 207.18 | 0.08 |
| J-208 | 1,900.00 | 0.14 | 1,975.19 | 18.27 | 0.08 |
| J-209 | 2,000.00 | 0.18 | 2,079.58 | 48.04 | 0.32 |
| J-210 | 1,890.00 | 0.00 | 1,866.80 | 72.19 | 0.01 |
| J-211 | 1,880.00 | 0.00 | 1,906.66 | 15.49 | 0.14 |
| J-212 | 2,000.00 | 0.00 | 2,038.15 | 75.08 | 0.15 |
| J-213 | 1,750.00 | 0.00 | 1,705.45 | 25.19 | 0.08 |
| J-214 | 1,900.00 | 0.00 | 1,902.78 | 96.01 | 0.95 |
| J-215 | 1,860.00 | 0.00 | 1,801.20 | 413.49 | 0.05 |
| J-216 | 1,800.00 | 0.00 | 1,801.48 | 8.24 | 0.06 |
| J-217 | 2,090.00 | 0.00 | 2,089.22 | 52.04 | 0.25 |

| | | | | | |
|---|---|---|---|---|---|
| J-218 | 2,000.00 | 0.82 | 2,088.03 | -59.45 | 0.05 |
| J-219 | 1,950.00 | 0.16 | 1,988.40 | 10.58 | 0.08 |
| J-220 | 1,900.00 | 0.25 | 1,987.95 | 360.17 | 0.02 |
| J-221 | 1,800.00 | 0.14 | 1,887.24 | -7.06 | 0.05 |
| J-222 | 1,750.00 | 0.15 | 1,787.06 | -0.15 | 0.02 |
| J-223 | 1,800.00 | 0.14 | 1,806.81 | -26.74 | 0.24 |
| J-224 | 1,760.00 | 0.19 | 1,786.71 | -86.7 | 0.26 |
| J-225 | 1,850.00 | 0.81 | 1,886.66 | -0.15 | 0.08 |
| J-226 | 1,900.00 | 0.09 | 1,991.51 | 21.14 | 0.05 |
| J-227 | 1,845.00 | 0.25 | 1,881.48 | 41.58 | 0.26 |
| J-228 | 1,800.00 | 0.48 | 1,801.19 | 0.19 | 0.48 |
| J-229 | 1,700.00 | 0.08 | 1,725.19 | 158.26 | 0.05 |
| J-230 | 1,900.00 | 0.18 | 1,956.26 | 94.08 | 0.00 |
| J-231 | 2,100.00 | 0.17 | 2,085.24 | 190.05 | 0.52 |
| J-232 | 1,990.00 | 0.08 | 1,981.08 | 305.01 | 0.98 |
| J-233 | 2,150.00 | 0.08 | 2,085.65 | 40.75 | 0.05 |
| J-234 | 2,050.00 | 0.48 | 2,085.42 | 75.19 | 0.90 |
| J-235 | 1,850.00 | 0.00 | 1,825.47 | 42.85 | 0.08 |
| J-236 | 1,980.00 | 0.00 | 1,909.21 | 80.37 | 0.05 |
| J-237 | 2,150.00 | 0.08 | 2,081.56 | 81.00 | 0.02 |
| J-238 | 1,950.00 | 0.49 | 1,985.12 | 48.01 | 0.26 |
| J-239 | 1,850.00 | 0.18 | 1,884.45 | 10.46 | 0.00 |
| J-240 | 1,750.00 | 0.15 | 1,781.05 | 110.56 | 0.05 |
| J-241 | 2,050.00 | 0.09 | 2,086.17 | 37.08 | 0.14 |

**Annexes H8:** Pressure Map of Nodes for Peak Hour Demand Scenario, EPS Analysis




**Watpro 4.0 simulation results**

**Annexes-K**: Final effluent summary

| Parameter | Criteria | Value | Unit |
|---|---|---|---|
| Disinfectants | | | |
| Effluent Chlorine | 4 | 2 | mg/L |
| Effluent Chlorine Dioxide | 0.8 | 0 | mg/L |
| Effluent Chloromines | 1 | 0 | mg/L |
| DBPs | | | |
| TTHMs | 100 | 0.0918659 | ug/L |
| HAA5s | 100 | 2.49309 | ug/L |
| Chlorite | 1 | 0 | mg/L |
| Total Giardia Reduction | 6 | 23.0313 | log(10) |
| Total Virus Reduction | 7 | 75.3254 | log(10) |
| Total Crypto Reduction | 2 | 2 | log(10) |
| Turbidity | 0.5 | 1.25 | NTU |

**Annexes-L:** process output summary

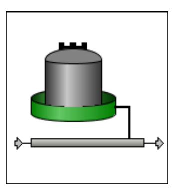
| | **Pr.Giar.Redn (log(10))** | **Cu.Giard.Redn (log(10))** | **Pr.Vir.Redn (log(10))** | **Cu.Virus.Redn (log(10))** |
|---|---|---|---|---|
| Influent | 0 | 0 | 0 | 0 |
| Disinfectant Addition | 90.568 | 94.153 | 87.294 | 75.482 |
| Chemical Addition | 85.265 | 82.845 | 79.128 | 69.25 |
| Flocculator | 12.1774 | 12.1774 | 43.5001 | 43.5001 |
| Settling Basin | 4.97602 | 17.1534 | 17.7753 | 61.2753 |
| Filtration | 0.229923 | 17.3834 | 0.80504 | 62.0804 |
| Contact Tank | 0.286176 | 17.6695 | 1.02227 | 63.1026 |
| Clear Well | 2.86176 | 20.5313 | 10.2227 | 73.3254 |
| | - | - | - | - |

**Annexes- M:** ct-disinfection parameters

| | Ct.cl2(mg /l*min) | Ctsum.cl2 | Ct.clo2(mg/l*min | Ctsum.clo2 |
|---|---|---|---|---|
| Influent | 0.0 | 0.0 | 0.0 | 0.0 |
| Disinfection addition | 0.0 | 0.0 | 0.0 | 0.0 |
| Chemical addition | 0.0 | 0.0 | 0.0 | 0.0 |
| flocculator | 30.0 | 30.0 | 0.0 | 0.0 |
| Settling basin | 12.2588 | 42.2588 | 0.0 | 0.0 |
| filtration | 0.5552 | 42.814 | 0.0 | 0.0 |
| Contact tank | 0.705016 | 43.5191 | 0.0 | 0.0 |
| Clear well | 7.05016 | 50.5692 | 0.0 | 0.0 |

**Annexes – N:** Chemical addition

**Layout 1-Chemical Addition**



**Input Parameters**

**Data Entry**

| | |
|---|---|
| Chemical Type | Alum (Aluminum Sulfate) |
| Chemical Dosage | 65 |

**Output Data**

| | |
|---|---|
| **Incoming Stream** | **eff_1** |
| **Properties** | |
| Flow Rate | 8510.45 |
| pH | 7.2 |
| TOC | 0.001 |
| UV254 | 0 |
| Temperature | 19.5 |
| Ammonia | 0 |
| Alkalinity | 0 |
| Hardness | 0 |
| Turbidity | 6.75 |
| **Ionic Species** | |
| Ca(aq) | 0 |
| Mg(aq) | 0 |
| Carbonates(aq) | -0.00472499 |
| CaCO3(p) | 0 |
| MgOH(p) | 0 |
| Other Anion (Ca') | 9.1734E-05 |
| Other Cation (Cb') | 6.3096E-08 |
| **TTHM, Chlorite/Chlorate** | |
| TTHM | 0 |
| CHCl3 | 0 |
| CHBrCl2 | 0 |
| CHBr2Cl | 0 |
| CHBr3 | 0 |
| Chlorite | 0 |
| Chlorate | 0 |
| **HAA** | |
| HAA5 | 0 |
| MCAA | 0 |
| DCAA | 0 |
| TCAA | 0 |
| MBAA | 0 |
| DBAA | 0 |

| | |
|---|---|
| **Outgoing Stream** | **eff_2** |
| **Properties** | |
| Flow Rate | 8510.45 |
| pH | 7.2 |
| TOC | 0.001 |
| UV254 | 0 |
| Temperature | 19.5 |
| Ammonia | 0 |
| Alkalinity | 0 |
| Hardness | 0 |
| Turbidity | 6.75 |
| **Ionic Species** | |
| Ca(aq) | 0 |
| Mg(aq) | 0 |

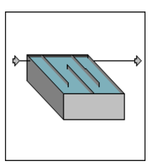
| | |
|---|---|
| | - |
| Carbonates(aq) | 0.00472499 |
| CaCO3(p) | 0 |
| MgOH(p) | 0 |
| Other Anion (Ca') | 0.00074791 |
| Other Cation (Cb') | 6.3096E-08 |
| **TTHM, Chlorite/Chlorate** | |
| TTHM | 0 |
| CHCl3 | 0 |
| CHBrCl2 | 0 |
| CHBr2Cl | 0 |
| CHBr3 | 0 |
| Chlorite | 0 |
| Chlorate | 0 |
| **HAA** | |
| HAA5 | 0 |
| MCAA | 0 |
| DCAA | 0 |
| TCAA | 0 |
| MBAA | 0 |
| DBAA | 0 |

**Process Values**

| | |
|---|---|
| Chemical Type | Alum (Aluminum Sulfate) |
| Chemical Dosage | 65 |

## Annexes-O: Contact tank

**Layout 1-Contact Tank**



**Input Parameters**

**Data Entry**

| | | | |
|---|---|---|---|
| Volume | - | | m3 |
| Surface Area | | 30 | m2 |
| Tank Level | | 5 | m |
| Baffling Description | baffled | | |

| | | |
|---|---|---|
| Include in Ct(Sum) | true | |
| **Measured Data** | | |
| Tracer Study Data | true | |
| Tracer Study Flow | 100 | m3/d |
| Tracer Study det. time(t10) | 30 | min |
| Tracer Study det. time(t50) | 30 | min |
| Chlorine Residual | 1.6 | mg/L |
| ClO2 Residual | 0 | mg/L |
| Measured Turbidity | 2 | NTU |

**Output Data**

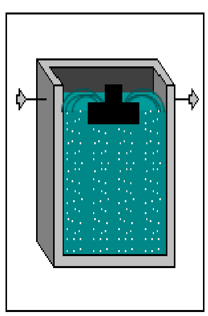
| | |
|---|---|
| **Incoming Stream** | **eff_4** |
| **Properties** | |
| Flow Rate | 8510.5 |
| pH | 3.1263 |
| TOC | 0.001 |
| UV254 | 0 |
| Temperature | 19.5 |
| Ammonia | 0 |
| Alkalinity | -37.41 |
| Hardness | 0 |
| Turbidity | 2.57 |
| **Ionic Species** | |
| Ca(aq) | 0 |
| Mg(aq) | 0 |
| Carbonates(aq) | -0.005 |
| CaCO3(p) | 0 |
| MgOH(p) | 0 |
| Other Anion (Ca') | 0.0007 |
| Other Cation (Cb') | 6E-08 |
| **TTHM, Chlorite/Chlorate** | |
| TTHM | 0.0898 |
| CHCl3 | 0.0898 |
| CHBrCl2 | 0 |
| CHBr2Cl | 0 |
| CHBr3 | 0 |
| Chlorite | 0 |
| Chlorate | 0 |
| **HAA** | |
| HAA5 | 2.4385 |
| MCAA | 0.0087 |
| DCAA | 0.6409 |
| TCAA | 1.789 |
| MBAA | 0 |
| DBAA | 0 |

| | |
|---|---|
| **Outgoing Stream** | **eff_9** |
| **Properties** | |
| Flow Rate | 8510.5 |
| pH | 3.1263 |

| | |
|---|---|
| TOC | 0.001 |
| UV254 | 0 |
| Temperature | 19.5 |
| Ammonia | 0 |
| Alkalinity | -37.41 |
| Hardness | 0 |
| Turbidity | 2 |
| **Ionic Species** | |
| Ca(aq) | 0 |
| Mg(aq) | 0 |
| Carbonates(aq) | -0.005 |
| CaCO3(p) | 0 |
| MgOH(p) | 0 |
| Other Anion (Ca') | 0.0007 |
| Other Cation (Cb') | 6E-08 |
| **TTHM, Chlorite/Chlorate** | |
| TTHM | 0.09 |
| CHCl3 | 0.09 |
| CHBrCl2 | 0 |
| CHBr2Cl | 0 |
| CHBr3 | 0 |
| Chlorite | 0 |
| Chlorate | 0 |
| **HAA** | |
| HAA5 | 2.4436 |
| MCAA | 0.0087 |
| DCAA | 0.6421 |
| TCAA | 1.7928 |
| MBAA | 0 |
| DBAA | 0 |

**Annexes-P:** flocculator

**Layout 1-Flocculator**



**Input Parameters**

| | | | |
|---|---|---|---|
| **Data Entry** | | | |
| Volume | | 360 | m3 |
| Baffling Description | Unbaffled | | |
| Include in Ct(Sum) | true | | |
| **Measured Data** | | | |

| | | |
|---|---|---|
| Tracer Study Data | true | |
| Tracer Study Flow | 4255.23 | m3/d |
| Tracer Study det. time(t10) | 30 | min |
| Tracer Study det. time(t50) | 0 | min |
| Chlorine Residual | 2 | mg/L |
| ClO2 Residual | 0 | mg/L |
| Measured Turbidity | 6.75 | NTU |

**Output Data**

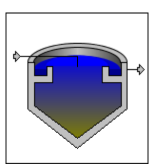
| | | |
|---|---|---|
| **Incoming Stream** | **eff_2** | |
| **Properties** | | |
| Flow Rate | | 8510.45 |
| pH | | 7.2 |
| TOC | | 0.001 |
| UV254 | | 0 |
| Temperature | | 19.5 |
| Ammonia | | 0 |
| Alkalinity | | 0 |
| Hardness | | 0 |
| Turbidity | | 6.75 |
| **Ionic Species** | | |
| Ca(aq) | | 0 |
| Mg(aq) | | 0 |
| Carbonates(aq) | | -0.004725 |
| CaCO3(p) | | 0 |
| MgOH(p) | | 0 |
| Other Anion (Ca') | | 0.00074791 |
| Other Cation (Cb') | | 6.3096E-08 |
| **TTHM, Chlorite/Chlorate** | | |
| TTHM | | 0 |
| CHCl3 | | 0 |
| CHBrCl2 | | 0 |
| CHBr2Cl | | 0 |
| CHBr3 | | 0 |
| Chlorite | | 0 |
| Chlorate | | 0 |
| **HAA** | | |
| HAA5 | | 0 |
| MCAA | | 0 |
| DCAA | | 0 |
| TCAA | | 0 |
| MBAA | | 0 |
| DBAA | | 0 |

| | | |
|---|---|---|
| **Outgoing Stream** | **eff_3** | |
| **Properties** | | |
| Flow Rate | | 8510.45 |
| pH | | 3.12634 |
| TOC | | 0.001 |
| UV254 | | 0 |

| | |
|---|---|
| Temperature | 19.5 |
| Ammonia | 0 |
| Alkalinity | -37.4119 |
| Hardness | 0 |
| Turbidity | 6.75 |
| **Ionic Species** | |
| Ca(aq) | 0 |
| Mg(aq) | 0 |
| Carbonates(aq) | -0.004725 |
| CaCO3(p) | 0 |
| MgOH(p) | 0 |
| Other Anion (Ca') | 0.00074791 |
| Other Cation (Cb') | 6.3096E-08 |
| **TTHM, Chlorite/Chlorate** | |
| TTHM | 0 |
| CHCl3 | 0 |
| CHBrCl2 | 0 |
| CHBr2Cl | 0 |
| CHBr3 | 0 |
| Chlorite | 0 |
| Chlorate | 0 |
| **HAA** | |
| HAA5 | 0 |
| MCAA | 0 |
| DCAA | 0 |
| TCAA | 0 |
| MBAA | 0 |
| DBAA | 0 |

# Annexes-Q: Settling basin

**Layout 1-Settling Basin**



**Input Parameters**

**Data Entry**

| | | |
|---|---|---|
| Volume | - | m3 |
| Surface Area | 72.45 | m2 |
| Tank Level | 5 | m |
| Baffling Description | baffled | |

| | | |
|---|---|---|
| Turbidity Removal Efficiency | 75 | % |
| Include in Ct(Sum) | true | |
| **Measured Data** | | |
| Tracer Study Data | false | |
| Tracer Study Flow | - | |
| Tracer Study det. time(t10) | - | |
| Tracer Study det. time(t50) | - | |
| Chlorine Residual | - | mg/L |
| ClO2 Residual | - | mg/L |
| Measured Turbidity | 7 | NTU |

**Output Data**

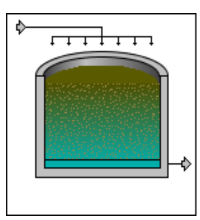
| | |
|---|---|
| **Incoming Stream Properties** | **eff_3** |
| Flow Rate | 8510.5 |
| pH | 3.1263 |
| TOC | 0.001 |
| UV254 | 0 |
| Temperature | 19.5 |
| Ammonia | 0 |
| Alkalinity | -37.41 |
| Hardness | 0 |
| Turbidity | 6.75 |
| **Ionic Species** | |
| Ca(aq) | 0 |
| Mg(aq) | 0 |
| Carbonates(aq) | -0.005 |
| CaCO3(p) | 0 |
| MgOH(p) | 0 |
| Other Anion (Ca') | 0.0007 |
| Other Cation (Cb') | 6E-08 |
| **TTHM, Chlorite/Chlorate** | |
| TTHM | 0 |
| CHCl3 | 0 |
| CHBrCl2 | 0 |
| CHBr2Cl | 0 |
| CHBr3 | 0 |
| Chlorite | 0 |
| Chlorate | 0 |
| **HAA** | |
| HAA5 | 0 |
| MCAA | 0 |
| DCAA | 0 |
| TCAA | 0 |
| MBAA | 0 |
| DBAA | 0 |

| | |
|---|---|
| **Outgoing Stream Properties** | **eff_5** |
| Flow Rate | 8510.5 |

| | |
|---|---|
| pH | 3.1263 |
| TOC | 0.001 |
| UV254 | 0 |
| Temperature | 19.5 |
| Ammonia | 0 |
| Alkalinity | -37.41 |
| Hardness | 0 |
| Turbidity | 7 |
| **Ionic Species** | |
| Ca(aq) | 0 |
| Mg(aq) | 0 |
| Carbonates(aq) | -0.005 |
| CaCO3(p) | 0 |
| MgOH(p) | 0 |
| Other Anion (Ca') | 0.0007 |
| Other Cation (Cb') | 6E-08 |
| **TTHM, Chlorite/Chlorate** | |
| TTHM | 0.0896 |
| CHCl3 | 0.0896 |
| CHBrCl2 | 0 |
| CHBr2Cl | 0 |
| CHBr3 | 0 |
| Chlorite | 0 |
| Chlorate | 0 |
| **HAA** | |
| HAA5 | 2.4339 |
| MCAA | 0.0087 |
| DCAA | 0.6398 |
| TCAA | 1.7855 |
| MBAA | 0 |
| DBAA | 0 |

**Annexes-R:** Filtration

**Layout 1-Filtration**



**Input Parameters**

**Data Entry**

| | | |
|---|---|---|
| Filter Type | Conventional | |
| Volume | 1604 | m3 |
| TOC Removal Efficiency | 0 | % |

| | | |
|---|---|---|
| UV254 Removal Efficiency | 0 | % |
| Turbidity Removal Efficiency | 88.95 | % |
| Include in Ct(Sum) | true | |
| **Measured Data** | | |
| Tracer Study Data | true | |
| Tracer Study Flow | 90 | m3/d |
| Tracer Study det. time(t10) | 30 | min |
| Tracer Study det. time(t50) | 30 | min |
| Chlorine Residual | 1.75 | mg/L |
| ClO2 Residual | 0 | mg/L |
| Measured Turbidity | 2.57 | NTU |

**Output Data**

| | |
|---|---|
| **Incoming Stream** | **eff_5** |
| **Properties** | |
| Flow Rate | 8510.45 |
| pH | 3.12634 |
| TOC | 0.001 |
| UV254 | 0 |
| Temperature | 19.5 |
| Ammonia | 0 |
| Alkalinity | -37.4119 |
| Hardness | 0 |
| Turbidity | 7 |
| **Ionic Species** | |
| Ca(aq) | 0 |
| Mg(aq) | 0 |
| Carbonates(aq) | -0.004725 |
| CaCO3(p) | 0 |
| MgOH(p) | 0 |
| Other Anion (Ca') | 0.0007479 |
| Other Cation (Cb') | 6.31E-08 |
| **TTHM, Chlorite/Chlorate** | |
| TTHM | 0.0896229 |
| CHCl3 | 0.0896229 |
| CHBrCl2 | 0 |
| CHBr2Cl | 0 |
| CHBr3 | 0 |
| Chlorite | 0 |
| Chlorate | 0 |
| **HAA** | |
| HAA5 | 2.4339 |
| MCAA | 0.0086679 |
| DCAA | 0.639764 |
| TCAA | 1.78547 |
| MBAA | 0 |
| DBAA | 0 |

| | |
|---|---|
| **Outgoing Stream** | **eff_4** |
| **Properties** | |

| | |
|---|---|
| Flow Rate | 8510.45 |
| pH | 3.12634 |
| TOC | 0.001 |
| UV254 | 0 |
| Temperature | 19.5 |
| Ammonia | 0 |
| Alkalinity | -37.4119 |
| Hardness | 0 |
| Turbidity | 2.57 |
| **Ionic Species** | |
| Ca(aq) | 0 |
| Mg(aq) | 0 |
| Carbonates(aq) | -0.004725 |
| CaCO3(p) | 0 |
| MgOH(p) | 0 |
| Other Anion (Ca') | 0.0007479 |
| Other Cation (Cb') | 6.31E-08 |
| **TTHM, Chlorite/Chlorate** | |
| TTHM | 0.089798 |
| CHCl3 | 0.089798 |
| CHBrCl2 | 0 |
| CHBr2Cl | 0 |
| CHBr3 | 0 |
| Chlorite | 0 |
| Chlorate | 0 |
| **HAA** | |
| HAA5 | 2.43852 |
| MCAA | 0.0086871 |
| DCAA | 0.640892 |
| TCAA | 1.78895 |
| MBAA | 0 |

**Annexes-S:** Water demand estimation of the town

### A) Per capita water consumption

Per capita consumption (l/c/d) = Annual consumption ($m^3$ * 1000l/$m^3$) / population figure * 365

=1,050,000*1000/137,171*365= 20.97 l/c/d

### B) Average water demand

$Q_{av}$ = no population * per capita water consumption

i.e. $Q_{av}$ = 137,171 * 75 l/c/d = 10,287,825 l/d

= 10,287.8 $m^3$/d

### C) Peak hour demand

Peak hour demand = PF * $Q_{av}$

$= 1.6 * 10,287.8\ m^3/d$

$= 16,460.4\ m^3/d$

**Annexes- T:** Hydraulic performance analysis of the distribution system

## A) Existing service reservoirs

Max.day demand = 1.2 * average day demand

$= 1.2 * 10,287.8\ m^3/d$

$= 12,345.36\ m^3/d$

Therefore, the current (2019) required service reservoirs volume capacity for water demand of Naqamte town was computed as:

Reservoir capacity = $Q_{max} * 1/3$
= 12,345.36 * 1/3
= $4115\ m^3$

**B) Pump capacity**

Pump Efficiency = Water Power $_{out,\ maximum}$ / Pump Power $_{in}$

= 31.2 KW/59 KW = 0.528= 52.8%

$$\text{Pump capacity} = \text{pump design capacity} * \text{effective pump operation time}$$

= 33 l/s * 24 hr/d = 2,851,200 l/d = $2,851.2\ m^3/d$

**Annexes U:** Evaluation of major unit processes capability

$$\text{a) Flocculation basin capability} = \frac{\text{Basin volume(m3)}}{\text{Detention time (min)}}$$

$$= \frac{720\ m3}{30\ min}$$

$= 24\ m^3/min * 1440 min/d$

$= 34,560\ m^3/d$

b) Sedimentation basin capability = Basin surface area ($m^2$) * surface over flow rate ($l/min/m^2$)

Basin surface area = 2basin * 15m (length) * 4m (depth)

$= 80\ m^2$

Surface loading rate = 25m/day

Hence, sedimentation basin capability = 80m$^2$ * 25 m/day = 3,000 m$^3$/d

c) Filtration basin capability = Filter bed area (m$^2$) * Filter loading rate (l/min/m$^2$)

The rated capability of the three filtration units was determined by assuming one of the filters out of service for cleaning. Thus, only three filter bed area was used.

Filter bed area = 3 filters * 4.8 m (length) * 3.6 m (width)

= 51.84 m$^2$

Filtration rate = 3.5 m/hr

Hence, Filtration basin capability = 51.84 m$^2$ * 7 m/hr * 24 hr/d

= 4,354.56 m$^3$/d

d) Chlorine contact time

CT = Concentration of free chlorine ($C_{mg/L}$) * contact time ($T_{minutes}$)

= 1.6 mg/l * 3min

= 4.8 mg-min/l

Therefore, to inactivate viruses and bacteria using free chlorine, the disinfection treatment required before the first customer must be at least 8 milligrams- minutes per liter (8 mg-min/L).

e) Contact tank

The effective contact time is related to both the volume of the contact tank and its design/structure. In the absence of any tracer test data for the tank, the effective contact time can be estimated from:

Effective contact time (minutes) = tank volume (m$^3$) x 60 x Df / flow (m$^3$/h)

Where: tank volume = length x width x minimum depth

= (10.745 * 5.5 * 3) m$^3$

= 177.3 m$^3$

Suppose that the baffling condition is average so that take $D_f$ = 0.5 and flow of 354.6 m$^3$/h (obtained from design report). Hence, substituting the values into the above equation (3.5);

Effective contact time (t) = 177.3 m$^3$ * 60 * 0.5 /354.6m$^3$/h

= 15 minutes

But, the residual chlorine concentration in the water leaving the tank is 1.6 mg/l.

Ct = Effective contact time (t) * residual chlorine concentration (mg/l)

Therefore, Ct = 15 minutes * 1.6 mg/l

= 24 mg-min/l

Therefore, the contact tank of ct is 24mg-min/l

**Annexes- V:** Evaluation of contact time for water system

Step 1: Determine the time available in the basin at peak flow

$$\text{Time(min)} = \frac{\text{basin volume (m3)} * \text{baffling factor}}{\text{peak hourly flow } (^{\text{m3}}/_{\text{min}})}$$

By taking the 177.3 $m^3$ of clear water tank volume, assuming that the baffling condition is average i.e. 0.5, and the peak hourly flow of the system is 99 l/s = 5.94 $m^3$/min.

Hence, Time (min) = 177.3 $m^3$ * 0.5/ 5.94 $m^3$/min = 14.9 min

Step 2: Determine the contact time available at peak flow

Available contact time (min mg/l) = Time (min) * chlorine concentration (mg/l)

= 14.9 min * 1.6 mg/l

= 23.84 min

Step 3: Find the required Contact Time (CT) from the tables at peak flow

Determine the CT required by the Environmental Protection Agency. By looking up the CT from the CT tables provided in the EPA of the Guidance Manual using the measurements that has been taken from the water quality expert; 6.5 of PH, 20$^o$c of temperature and 1.6 of chlorine concentration i.e. from annex-D

Hence, the value from the table mean that the required contact time is, $CT_{99.9\,=}$ 50 min

Step 4: Does your water system meet CT requirements?

Compute the inactivation ratio by dividing the actual contact time by required contact time. If the ratio is greater than 1, then the water system met its contact time requirements.

$$\text{Inactivation ratio} = \frac{\text{Actual contact time}}{\text{required contact time}}$$

$= CT_{calc} / CT_{99.9}$

$= 23.84 \text{ min} / 50 \text{ min}$

$= 0.476$

**Annexes- W:** Evaluation of existing plant efficiency

The flow rate, 99 l/s = 356.4 $m^3$/hr or 8,553.6 $m^3$/day. But it is identified that current practical operation works at 170 x 1 pump = 170$m^3$/hr or 4,080 $m^3$/day. Note that it doesn't bring any difference if it starts 2 sets of raw water pumps because due to the dissolved iron and manganese as well as other organic constituents in the raw water, it cannot expect capacity of the clarifiers to hold more than this.

But, only 2,846 $m^3$ of clean water every day in the distribution system (the current plant capacity). However, the treatment plant efficiency of the town can be estimated as below;

$$\text{plant efficiency rate} = \frac{\text{water consumed}}{\text{water produced}} * 100$$

$$\text{Plant efficiency rate} = \frac{2846}{4080} * 100 = 69.75\%$$

**Annexes –X:** List of questionnaire

LIST OF QUESTIONNAIRE

**Questionnaire to assess the main factors of water loss in the town water supply system**

**Name:** Nagalo Inge **Date** 10/7/2018

1. Do the customers get water continuously?
   A) Yes
   B) No
2. Depending on question (1), if so, by what system water is supplied for customers?
   A) Intermittently
   B) Continuously
3. Is water demand and number of population of the town balanced?
   A) Yes, it is
   B) No, it is not
4. Depending on question (3), do the town faced with scarcity of water supply?
   A) Yes
   B) No
5. Is water distribution network encountered with water loss?
   A) Yes
   B) No
6. Depending on question (5), if so, what are the major factor contributes to water loss in the system?
   A) Pipe burst
   B) Metering error
   C) Illegal connections
   D) Poor maintenance practices
   E) All
7. Depending on question (6), which factor happen frequently?
   A) Pipe burst
   B) Metering error
   C) Illegal connections
   D) None
8. Depending on question (7), so, do the problems dealt with as soon as it happened?
   A) Yes
   B) No
9. Do the water supply authority have leakage management strategy?
   A) Yes
   B) No

**Annexes-: List of Pictures**

**Figure N-1: WTP**

**Figure N-2: Filter tank under expansion (left) and RSF (right)**

Figure N-3: Chemical building

Figure N-4: Field visit; pressure and GPS reading