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Assessment of Water Supply Coverage and Water Loss in Distribution System

(Case Study Debre Brehan Town)

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Abstract

Losses in the urban water supply networks have become a growing concern and there are several alternatives for the quantification, detection and monitoring of water losses. However, water loss is a great challenge in developing countries including Ethiopia as well as Debre Brehan town. Peoples do not have enough access to safe and reliable water coverage due to highly water loss in the distribution system and other utility problem. Therefore, this study mainly focuses on to assess the status of water supply coverage and water losses in Debre Brehan town. Statistical analysis with regards of field observation, different literature revision, pressure measurement and discussions with water service personnel were conducted to analyze the water supply coverage and water loss in the town. Water CAD software was adopted to examine the hydraulic parameters and water supply elements in the distribution network. The finding of this study showed that the average connection per family and average daily per capita water consumption of the town was estimated in the order of 32% and 23.24 l/c/d respectively. As water loss estimation result from the total production of water in the town about 37.40% of is non-revenue water. Among this, 6.78% is real loss that includes leakage and pipe burst. Whereas, 30.62% was apparent loss more considerable and accounted for meter inaccuracy, poor maintenance practice, legal unbilled connection and illegal connection. Moreover, from the model analysis result different problems were observed. These were poor efficiency of pumps and storage tanks, high and low pressure beyond to the recommended value. In general, the main reasons for the low water supply coverage of town was poor water network management, lack of attention and budget to develop additional water source, high level of water loss and low performance of the existing distribution system. Thus, well organized network management practice, giving more attention to water loss and reduction strategies, constructing additional source of water and installing standby generator at all existing pump station are some important remedial measures to improve the water supply coverage of the town.

Key words: water supply coverage, water loss, water supply distribution network, water CAD

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LIST OF ACRONYMS

AAWSA	Addis Ababa Water and Sewerage Authority
AWRDO	Amhara Water Resource Development Office
ADB	African Development Bank
ADD	Average Day Demand
AICD	Automatic Implantable Cardioverter Defibrillator
BWD	Base Water Demand
CAD	Computer Aided Design
CARL	Current Annual Real Loss
CSA	Central Statistics Agency
DBWSS	Debre Brehan Water Supply and Sewerage office
DCI	Ductile Cast Iron
DHS	Demographic and Health Surveys
DMAs	District Mater Areas
EPS	Extended Period Simulation
FDRE	Federal Democratic Republic of Ethiopia
ILI	Infrastructure Leakage Index
IWA	International Water Association
MICS	Multiple Indicator Cluster Surveys
MNF	Minimum Night Flow
MoWR	Ministry of Water Resource
NRW	Non Revenue Water
NGOs	None Governmental Organizations

PF	Public Fountain
PRV	Pressure Reducing Valve
SI	System International
UARL	Unavoidable Annual Real Loss
UFW	Unaccounted For Water
UNICEF	United Nation Children Fund
UWDM	Urban Water Demand Management
WAEA	Water for Agriculture and Energy in Africa
WDN	Water Distribution Network
WDS	Water Distribution System
WHO	World Health Organization
WSDS	Water Supply Distribution System
YCP	Yard Connection Private
YCS	Yard Connection Shared

1 INTRODUCTION

1.1 Background

Transporting water from the source to water customers areas started 3500 years ago and ‘‘the history of water distribution technology is just a story’’ (Walski, 2003). It is still being continued and grown to sophisticated model designed water supply distribution networks.

About 2.997% is locked up in ice cap or glaciers. Only 0.003% of the earth’s total volume of water is easily available to us. The fresh water we use comes from two sources: surface and ground water (Miller, 1994).

The most important use of water is to support human life. Availability of potable water is one of the most important criteria of high standard of living (Polevoy, 2003). Ethiopia is naturally endowed with abundant water resources that help to fulfill domestic requirements, irrigation and hydropower. With its per-capita fresh water resources estimated at $1924m^3$ makes one of the Sub Saharan African (SSA) countries endowed with the largest surface fresh water resource (MoWR, 2002). The annual rainfall runoff and ground water resource estimated 122 and 2.50 billion m^3 , respectively (WAEA, 2008). However, with all this potential, Ethiopia is one of the countries with low access rate to drinking water and sanitation in the world. Nearly 50 and 65 million people (which are 62% and 81% of the total population respectively) lack access to safe water and sanitation in Ethiopia respectively (WHO and UNICEF, 2010). The main problem that developing countries have been facing to provide access to save water for their citizen’s was shortage of resource. Moreover, the capacity of the citizen has to pay for water that fully recovers the cost was very limited. Problem in providing satisfaction water supply to the rapidly growing population especially that of the developing countries were increasing from time to time. Water supply coverage system in urban areas are often unable to meet existing demands were not available to everyone rather some consumer take disproportional amount of water and the poor is the first victim to the problem (Bereket, 2006). Moreover, managing and reducing losses of water at all level of a distribution remains one of the major challenges facing many water utilities in most developing countries including Ethiopia. As a result of the overall shortage of water many water utilities were faced a problem in distribution system. Besides, to this poor management of the existing infrastructure asset increases the level of water losses in water supply (Mebet, 2007). Although there are many reasons for minimizing losses in municipal water distribution networks, perhaps the most important one relates to quality of service. Additional, during drought periods, system with a high losses index cannot be properly manage and may demand frequency service

interruption. Losses from a water distribution network can be determined by adopting several approaches. By using a field studies concept of yearly balance and minimum night flow (MNF) assessment, possibly in combination with “burst and background losses estimation”, the total value of leakage in water supply networks (at district meter area, DMA, level) can be evaluated and its component was determined (Tabesh et al., 2008)

Water supply distribution networks are structures used to convey potable water from treatment plants to the community or water consumers for different demands including firefighting. Even though they may differ in size, most distribution systems have common basic components like pipes, pumps, valves, tanks, reservoirs and other appurtenances. They are designed to deliver water at adequate discharge and pressure according to demands and specific quality (A. Elsheikh Mahmoud et al., 2013). Water Distribution Systems play an important role in modern societies being its proper operation directly related to the population’s wellbeing (Muranho et al., 2013). The main issue that makes the water distribution structures to seek the attention of the engineering field is their design, operation and management to serve the community in an efficient and reliable manner now and in the future, which is also a global concern.

Hydraulic analysis of flows and pressures in a distribution system has been a standard form of engineering analysis since its development by Hardy Cross in 1936. Water distribution system computer models have been in use since the middle 1960s and have evolved into sophisticated, user-friendly tools that are capable of simulating large distribution systems (Walski et al., 2001).

Pipe burst and Leakage are often a large source of unaccounted for water. And results from improper pipe material selection and either lack of maintenance or failure to renew ageing systems. Pipe burst may also be caused from Ices formation and poor management of pressure zones, which result in pipe. Although, some leakage may go unnoticed for a longtime, detection of visible leakage also requires good reporting which includes some level of public participation. Indifferent attempts and research, works have been also made in different parts of the countries by different governmental organizations, individuals, and voluntary sectors to identify the causes for failing of adequate and sustainable urban water supply system. Previously conducted studies identified the major causes expect physical loss ; however, it is not possible to generalize for other urban areas like those Debre Brehan town where the problem is serious but not such conducted yet. Therefore, the study will focus to assess water supply coverage and water loss in the supply distribution system.

1.2 Statement of the problem

Currently, the water supply system in developing countries does not meet the need of people and industries. High levels of water losses are indicative of poor governance and poor physical condition of the water distribution system. According to (Dighade et al., 2014) ,The amount of water loss in water distribution systems varies widely between different countries, regions and systems from as low as 3-7% to as high as 50 % of distribution input volume in the well maintained systems of developed countries and less maintained system in developing countries respectively.

Debre Breha town has been passed through various social and economic progress. However, increasing population, growing urbanization and socio-economic change of the people, have pushed up the demand for water extremely high in terms of quantity and quality. This clearly calls for the expansion and improvement of basic water supply service to give proper and timely response to the town water demand. However, in the town there is water distribution, reliability and production problem. The level of water production with the existing power system is not proportional with the town water demand. In addition to this among ten bore holes only five have standby generator when electric power is pause the water production is reduces by more than half. As a consequence, the towns“ people suffer due to shortage of potable water.

In addition, Debre Brehan town water supply office had many problems as an institution to ensure a sustainable water supply. Some of them are, have no well-equipped technically qualified technicians, has poor administration of the water supply system, budget shortage, lack of manpower to handle policy and regulatory issues and to plan, operate and maintain the service, poor institutional organization and lack of coordination with stakeholders were some of them. Moreover, the involvement of the private sector or civil society in the design, construction, operation and maintenance of water supply systems was very low.

The other problem in town is high amount of water loss from the distribution system with frequently pipe burst and other Causes of loss. According to statistical analysis of (2011), 43.43% is loss from the total production of water and uncounted for water for the last five year. As result of this high water loss and mentioned above problem water supply and demand not balanced in the town. Therefore, this study was conducted to assess the water supply coverage and water loss in the distribution system by using statistical surveying and water CAD software.

1.3 Research questions

- ✚ What is the level of water supply coverage and distribution in the town?
- ✚ What is the level of water connection per family in the town level?
- ✚ How much water is produced and distributed to the network system?
- ✚ How much water is lost in the entire town while compared with the water produced?
- ✚ What are the possible causes of water losses in the water distribution system?
- ✚ What are the possible solutions to reduce the loss?
- ✚ What are the key hydraulic parameters affecting the performance efficiency of the water distribution network?

1.4 Objective of the study

1.4.1 General objective

- The general objective of the study is to assess the Water Supply Coverage and Water Loss in Water Supply Distribution System in the Case of Debre Brehan Town.

1.4.2 Specific objectives

- ✓ To analyze the domestic water supply coverage and distribution
- ✓ To assess water loss in water supply distribution network.
- ✓ To assess the causes of water loss in the town water supply distribution system.
- ✓ To recommend water loss reduction strategies in the town water supply distribution system.
- ✓ To evaluate hydraulic parameters and water supply elements in the distribution system.

1.5 Justification of the study

Water is the most essential component of living creature. Water utility Engineers develop water supply system to use water safely for various purposes. A water supply system is an infrastructure for the collection, transmission and distribution of water to consumers, thus it is composed of different hydraulic elements such as pipes, reservoirs, storage tanks, pumps and valves. The main purpose of water supply system is providing adequate amount of potable water to consumer at required pressure. Today, water utility department of municipalities are struggling to meet the water demand of consumers.

The rapid growth of population and expansion of factories in Debre Brehan town increases water supply demand and also there is huge amount of water loss in the distribution system as result

shortage of water in the town has been observed so the water utilities obligate to make new investments for meeting additional demands. Water distribution networks are required to supply water to domestic, commercial, and industrial entities above or at threshold pressure with consumer demands that vary throughout the day, week, season and year.

1.6 Scope of the study

The objective of this research is to present the fundamental concept of hydraulics applied to Debre-Brehan town water supply network, in order for municipal officials of the town to a better evaluation and decision making of water distribution and delivery systems. Therefore, the research work was limited to assess the water distribution network (from clear water well to distribution end point) of Debre-Brehan town water supply system in North Shoa Zone Amhara region of Ethiopia and it mainly focused to identify the water supply coverage, water loss and management strategy and hydraulic performance of the town water distribution system. This was achieved with discussion with the town water utility personnel to gather relevant information in the subject area, water supply coverage and loss analysis with the aid different statistical analysis and hydraulic modeling (Water CAD software).

1.7 Limitation of the study

The limitation that encountered during data collection and analysis of this study were;

- Debre Brehan water supply office have no organized and essential data like pipe burst size during burst, due to this unable to calculate water loss through the crack of pipe.
- There is no water meter laboratory in the town to estimate water loss through meter inaccuracy, so for this study water loss due to meter inaccuracy was calculated by asking information from Addis Ababa water meter laboratory Lamberet Brach with the aid of reviewing literatures.
- The distribution pipe system of the town have no organized pipe and nodal data. Hence, difficult to model the whole existing network by using primary survey data, therefore, only 53.41km main and distributary pipe line data surveyed and used for net-work model building.

2 LITRATURE REVIEW

2.1 Water supply distribution system

One of the principal roles of public work is providing water in sufficient quantity to users. Water supply and distribution is a complex system and that exists to satisfy the various needs of peoples. Whereby, it consists of various components of physical assets including reservoirs, pipes, pumps, and different hydraulic controlling accessories that make up the water distribution system. It is generally desired that water should be supply continuously in the required quantities with adequate pressure and flow from sources to all customers. However, occasional disruptions due to failures of their system components and variation of demands may occur over the service life (Jalal, 2008). Problems in providing satisfactory water supply to the rapidly growing population especially that of the developing countries is increasing from time to time. Water supply system in urban areas are often unable to meet existing demands and are not available to everyone rather some consumers take disproportionate amounts of water and the poor is the first victim develop and expand water supply projects and one of the difficulties among the other is managing and reducing losses of water at all levels of a distribution system. As a result of the overall shortage of water many cities are faced a problem in distributing the available water impartially among the residents. Besides the poor management of existing infrastructure asset increases the level of water losses in water supply. As this research deals with overall coverage of water supply, cause and mitigation measure for water loss were identified in the distribution networks at Debre-Brehan town level.

2.2 Urban water demand and coverage

2.2.1 Water demand

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Walling ford HR.2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use. Water demand management refers to any socially beneficial action that reduces average or peak water withdrawals or consumption form either surface or ground water, consistent with the protection or enhancement of water quality (Tate, 2000). According to Rothert and Macy (2000), water demand management is the adaptation and implementation of a strategy by an institution to influence the water demand and usage in order to meet any of the following objectives: economic efficiency, social development and social equity.

Urban water demand is classified in to different category that domestic water demands that included in-house-use and out-of -house-use is among the others. In-house-use includes demands for cooking sanitation, house cleaning, laundry and car washing while out-of-house-use includes like garden watering, swimming pools, public stand pipes for public uses and fountains, etc. Urban water demand is usually quoted in terms of liter per capital per day (1/capita/day). Despite the variation in residential indoor water use from household to household, a typical pattern (referred to as the water use profile) can be developed to provide a reasonable representation of indoor water use, based on the different indoor water use components (kitchen, bathroom, laundry, and toilet) and household occupancy (Mitchell et al, 2000). In many African cities urban water demands are often homogeneous owing to a range of levels of services occurring within the same urban area. Levels of service can vary from household connections to standpipes or to no service at all (Jalal, 2008).

2.2.2 Declining coverage of utility water

Water supply coverage provides a picture of the water supply situation of one specific country or city and helps to compare one country with others and the inter and intra city distribution with in specific country. The percentages of population with or without piped water connection are a relevant indicator to compare the coverage of water supply in urban areas. Although the water supply coverage is better in urban areas while compared with the rural, the actual water supply coverage in cities of developing countries in general and African cities in particular is very low while compared to the demand (Jalal, 2008).

Piped water reaches more urban Africans than any other form of water supply. But not as large a share as it did in the early 1990s. The most recent available data for 32 countries in the AICD DHS/MICS database suggests that some 39 percent of the urban population of Sub-Saharan Africa is connected to a piped network, compared with 50 percent in the early 1990s (table 2.1). Public stand posts, also supplied by utilities, are the second most widely used source, serving 24 percent of the population. Analysis suggests that the majority of those who lack access to utility water live too far away from the distribution network, although some fail to connect even when they live close by.

Table 2.1: The evolution of urban water supply sources in Africa Percentage of urban Population accessing various water sources

Year	Piped water	Stand posts	Wells/boreholes	Surface water	Vendors
1990–95	50	29	20	6	3
1996–2000	43	25	21	5	2
2001–05	39	24	24	7	4

Source: Banerjee et al (2008)

Most city dwellers who do not obtain their water from a utility get it from wells and boreholes, which are the primary source of water for 24 percent of Africa’s urban population. In some countries, such as Chad, Mali, Nigeria, and Sudan, wells and boreholes constitute the principal source of urban water supply. Only about 7 percent of urban residents rely for drinking water on lakes, ponds, springs, or other forms of surface water. Vendors currently serve about 4 percent of the urban market, but the percentage is much higher in some countries, including Mauritania (32 percent), Niger (21 percent), Chad (16 percent) and Nigeria (10 percent). Why has piped water coverage declined in urban Africa? Rapid population growth and rampant urbanization have put enormous pressure on utilities. Most of the population growth has occurred in per-urban slum neighborhoods, and utilities have not been able to extend their networks fast enough (Banerjee et al, 2008).

2.2.3 Urban water demand management

UWDM measures offer multiple benefits. Reductions in water demand not only make available the additional amount of water for serving the unserved in the urban areas but also reduce the cost of treatment (chemical use) and energy and defer the requirements for high capital investment for water supply infrastructure development. UWDM approaches and measures are often cost-effective and environment friendly (including less water withdrawals from streams and aquifers) compared with supply- driven water management. UWDM reduces the generation of pollutants and therefore the requirements for new or expanded wastewater treatment systems. It also enhances the development and adoption of new technologies and ultimately leads to financially sustainable water systems. Table 2.2 summaries five main UWDM approaches and related activities. Depending on the local circumstances, application of one or more of these approaches would be necessary to achieve sustainable water management in an urban area.

In general, the commonly applied UWDM measures can be grouped into three main categories:

- I. Structural and technical measures [nonrevenue water (NRW) and leakage control, use of water-saving devices, water meter management, using alternative water resources].
- II. Economic and financial measures (pricing of water, taxes and incentives).
- III. Socio-political measures (legal framework and regulations promoting water conservation, educational programmes, awareness campaigns, demonstration projects).

This clearly shows that UWDM is a multidisciplinary and multidimensional activity that requires active engagement of all stakeholders involved in the urban water sector such as; government agencies, water utilities, donors, private sectors, NGOs and the beneficiary community or consumers (S. K. Sharma and K. Vairavamoorthy, 2009).

Table 2.2: Urban water demand management approaches and related activities

No	UWDM approach	Activity
1	Increase system efficiency	No change in usage, but change in system operation Reduction of water loss in the distribution system (leak detection and repair, pressure management and control, water meter Management)
2	Increase end-use efficiency	Less resource use by consumers by using water advertising, awareness campaigns and education and use of water-efficient, devices and systems (low-volume flush, water-saving shower head and washing machine, water-efficient urinal, dish washer, etc.). Water efficiency considerations in the planning, design and construction of homes and buildings
3	Promote distributed sources of supply	Providing service via other local water resources that are not being used; Encouraging rainwater use and grey water reuse, water recycling and reuse in industries
4	Substitute resource use	Providing the same service without resource use e.g. waterless sanitation, low water-use garden plants and shrubs, plants adapted to local rain fall
5	Improve the market on resource usage	Full cost pricing of water, universal metering; using financial and economic instruments (tax, rebates, subsidy and loans), Informing consumers about the full cost of water and impact of excessive use of water resource

Source: adapted from S. K. Sharma and K. Vairavamoorthy (2009).

2.3 Water loss

Water loss occurs on all the systems. It is only the volume that varies, and it reflects the ability of a utility to manage its network. The water losses consist of real and apparent losses. The real losses consist of water lost through burst pipes, leaking joints, fittings, service pipes, and connections. The apparent losses result from illegal connections, under registration of customers meters, inaccurate meters, stopped meters, vandalized meters, bypassed meters, billing errors, inadequate meter reading policy, bribery and corruption of meter readers (Farley, et al., 2008). To understand the reasons why, how and where water is being lost; the managers have to carry out an appraisal of the physical characteristics of the network and the current operational practice. The condition of the infrastructure and the renewal or rehabilitation policy is perhaps one of the main reasons for the variation in leakage across the world. This problem is more pronounced in the developing countries with ageing infrastructure. A high level of real loss reduces the amount of precious water reaching customers, increases the operating costs of the utility and makes capital investments in new resource schemes larger. Reducing water losses is a special concern of every water supply utility (Dighade et al., 2014).

2.4 Components of water loss

Water losses in the distribution system are categorized as either real losses (physical) or apparent (commercial) losses. Apparent losses occur due to illegal use, inaccuracies in metering, meter reading errors, data handling and billing errors, and have a negative impact on utility revenue and accuracy of water usage data (AWWA, 2009).

2.4.1 Physical /real/ loss

‘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 towns’ water distribution system’ (Farley, et al., 2008).

2.4.1.1 Leakage in the distribution system

Leakage from water distribution networks has been drawing the water supply industry’s attention. This is mainly because leakage causes economical loss, contamination risk, and excessive environmental load in terms of water resources and operational energy consumption. Naturally, a number of leakage detection methods have been developed (Wu et al., 2012). In particular, leakage is a serious problem for water utilities of growing cities in developing countries. In fact, a large part of supplied water is lost as leakage from their existing water distribution networks while they are

expending much effort building new water treatment plants to meet the growing demand for water supply. Hence, leakage reduction is very beneficial. In particular, quick reduction is better from an economical point of view. In recent years, leakage detection methods based on steady-state hydraulic network models have been actively studied and with Applying their method to a real water distribution network and attained successful results (Wu et al., 2012).

2.4.1.1.1 The effective factors in causing leakage

The U.F.W and leakage in the water supply system and the urban water distribution networks have been paid attention in many countries. In recent three decades good experiences in theoretical and executions in decreasing of the water leakage have been obtained through the scientific and systematic planning. Fortunately, in Iran, this subject has been dealt with for more than one decade. The first step was preparing a national development plan for upgrading the urban water distribution in the second development plan of the country. The second step has been done by controlling offices of the U.F.W in the water and waste companies of the country in which the study of decreasing the water wasting has been paid. Many factors are involved in the leakage detection of the water in the network. Some of these effective factors has been mentioned as follows (Saghi, 2015).

- The Material of the Pipes
- The Age of the Pipes
- The Diameter of the Pipes
- The Pressure
- The Movement of the Soil around the Pipe
- Hit
- Using Unsuitable Materials for the Basis and Coverage of the Pipes
- Incorrect Installation
- Water Hammer Hit
- Clogging the Components Joints and Pipes
- The Depth of Placement of the Pipes
- The Effect of Temperature
- The Pressure of the Cars on the Surface of Roads and Ground
- The Movement of Soil
- The Damages to the Pipes by the Other Service Organizations
- Poor Quality Connections and Nonstandard Plumbing

- The Summit of Ground
- Climate Conditions

2.4.1.2 Pipe break /burst/ in water supply system

Pipe burst is one of the key issues that affect urban water distribution systems, and can lead to water supply interruption, loss of lives, property damage, and water quality problems. If the time of the pipe burst incidents can be anticipated beforehand, a pipe network maintenance plan can be formulated in advance to avoid the accidents. Pipe bursts can be broadly attributed to hydraulic and non-hydraulic factors. The hydraulic factors are the hydraulic transient shock and cavitation caused by the operation of pumps and valves. The non-hydraulic factors include pipe stress, pipe corrosion, the quality of construction, foundation failure, etc. For hydraulic factors, the vaporization phenomenon occurs when the pressure inside the pipe falls below the vapor pressure of the water; this will form a water hammer with water column separation and cavitation. The water hammer produced as a result of cavitation is different from the one from a traditional pump and valve opening or closing on the mechanism, and the current water hammer protection devices cannot function effectively (Xiong et al., 2003). In addition, the air sucked in by the exhaust valves, the water vapor generated by the negative pressure, as well as the air separated out from the water, will be compressed at the top of the pipe. The air can be divided into dispersion airbags by the surge, which will cause the pipe pressure to oscillate and shock the wall continuously, eventually resulting in pipeline damage. Air valves can resolve the problems in the pipes. The main reason for pipe bursts is due to a lack of air valves or air valve failures. In terms of non-hydraulic factors, underground pipelines will suffer from longitudinal and circumferential tensile stress, circumferential bending and socket cracking stress due to overburden pressure, water pressure, and temperature changes (Kim et al., 2012).

2.4.2 Commercial /apparent/ loss

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 (Farley, et al., 2008). 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). Therefore, ‘Apparent losses can amount to a large volume of water than physical losses and often have a greater value, since reducing apparent losses increases revenue,

whereas physical losses reduce production costs. For any profitable utility, the water tariff will be higher than the variable production cost and sometimes up to four times higher. Thus, even a small volume of apparent loss will have a large financial impact' (Farley, et al., 2008).

2.4.2.1 Water meter errors

Customer meter errors include errors due to accounting procedure and errors due to under or over registration of the meters. Many countries especially developing countries are experienced losses of water due to under registration of meter that many of them put meter replacement policies to alleviate the problem. The selection of customer meter types and classes may be limited by water quality considerations, as well as technical and economic considerations, economic replacement policies for residential. Meters based on selective testing programs in the National Reports generally indicate changeover periods between 5 and 10 years. Where customers are served by way of roof tanks, the probability of customer meter under-registration is increased, because of the tendency for a greater part of the consumption to pass through the meter at rates less than the Q minimum specified for the meter (Lambert, 2003).

2.5 Methods of measuring and comparing water loss

2.5.1 Measuring water loss

The unaccounted for water (UFW) expressed as percentage of the total consumption and the minimum night flow (MNF) per connection are the most commonly used methods of measuring losses. UFW is the measure of losses over a period as the difference between the amount of water put in to a system and the metered or estimated quantity of water taken by consumers, while MNF is an indicator of the probable rate of losses at a given time.

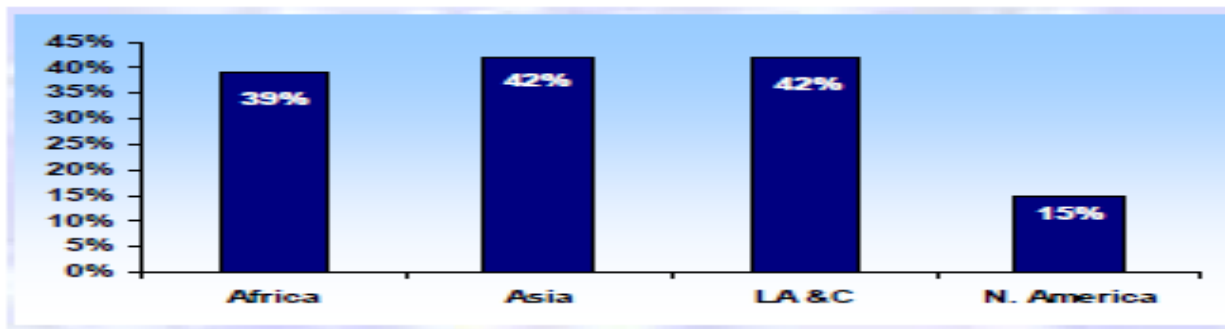


Figure 2.1: mean UFW in Large Cities in Africa, Latin America and the Caribbean and North American

Source: Global Water Supply and Sanitation Assessment 2000 (WHO-UNICEF)

Night flow measured in moderately sized sectors (up to around 3000 service connections) are extremely useful for identifying the presence of existing unreported leaks and bursts, and the occurrence of new ones. However, continuous night flows can also be used for assessing annual average real losses (Farley and Trow, 2003).

Unaccounted for water is a useful indicator of probable losses, but it may overestimate them because supply meters tend to under-record consumption. In UK, figures for unaccounted for water tend to be unreliable because the un-metered consumptions have to be estimated and can be 10% in error. Attempts to compare the performance of different undertakings by measuring some uniform figure for domestic consumption can be misleading. Many factors influence unaccounted for water and differ from one undertaking to another, standards of housing, rates of occupancy, age of mains, length of mains per 1000 population served proportion of trade and bulk supplies, ground condition, etc. (Twort A.C. et al., 1994) The minimum night flow (MNF) per property connection is a better indicator of loss rates on part of a system. However, figures of this type are affected by the characteristics of an area; in dense urban areas there will be more blocks of flats with large storages which may fill at night. Nevertheless, the MNF is a good direct indicator of the state of parts of a system (Twort A.C. et al., 1994).

On the other hand, Weimer referring to fully metered situations, considers that the annual water balance can initially only be taken as a guide as the calculations are susceptible to errors, analyses show this uncertainty in the calculated annual losses to be +/-46% (Lambert and Wallace, 1993). Different countries use different methodologies to evaluate the losses like the U.K. leakage practitioners and planners consider leakage almost exclusively in terms of night flow rates, rather than as a calculation of annual losses as in West Germany. Each method has its respective merits. 'Annual losses' are used for retrospective assessment of overall performance and long term demand forecasting. 'Night flows' are used by practitioners responsible for leakage control and prioritization of leakage control activities. Any conceptual model therefore needs to be able to link night flows with annual losses in a consistent manner (Lambert and Wallace, 1993). Although percentage figure are really meaningful when comparing different organizations, they can be used to indicate the extents of reduction of water loss by a single water supplier (WHO, 2001).

2.5.1.1 Estimating water loss from discovered leaks

Losses from leaks that are discovered and repaired should be measured to determine the rate of loss and the total volume lost during the life of the leak. Three methods are suggested (from ‘‘Leak Detection Productivity’’ by Douglas S.Greeley (AWWA California Nevada section, 1992).

- Use a container of known volume.
- Use a hose and a meter.
- Calculate losses using modified orifice and friction formula.

The first method, sometimes known as the bucket and stop watch method is as simple as its name. Hold a container against the leak for a predetermined time. Time is recorded by a stopwatch. Measures the water captured with a measuring cup or other container of known volume and then converts time and volume to l/min. The second method requires connecting a hose to the leak and directing the flow through a meter. The third method is the simplest to perform in the field but requires calculation. This method is often helpful for large leaks where the flow is too great to measure and the main must be valve off. It requires that the size and shape of the hole shall be measured and the line pressure will be determined. A pressure gauge or a hand held blade pedometer could be used to determine the pressure of the water coming from the leak or a nearby fire hydrant. This method also uses some assumptions regarding the shape of the hole that may introduce error. For losses from such items as a pipes or broken taps, Greeley assumes an orifice coefficient of 0.80 and calculates flow in gallons per minute from the formula:

$$Q = \left(\frac{43767}{1400} \right) * A * \sqrt{P} \dots\dots\dots (2.1) \text{ Equation to estimation of leak from Transmission mains}$$

Where, Q= flow in gallons per minute

A= the cross sectional area of the leak in square inches and

P= the pressure in pounds per square inch.

2.5.2 Comparing water loss

The amount of water loss differs from country to country, city-to-city and even from network to another network within one city. Different countries use different indicators to evaluate their status in comparison with other and to compare the distribution system in order to take action based on the level of losses. As stated above comparison using UFW expressed as a percentage has limitation when used for comparison as it highly depends with the volume of the water produced. The traditional performance indicators of water losses are frequently expressed as a percentage of input volume.

However, this indicator fails to take account of any of the main local influences. Consequently it cannot be considered to be an appropriate performance indicator (PI) for comparisons (WHO, 2001). Depending upon the consumption per service connection, the same volume of real losses/services connection/day, in percentage terms, is anything from 44% to 2.4%. Thus countries with relatively low consumption like the developing countries, can appear to have high losses when expressed in percentage terms in contrast percentage losses for urban areas in developed countries with high consumption can be equally misleading (Farley and Trow, 2003). To avoid for the wide diversity of formats and definitions related to water loss, many practitioners have identified an urgent need for a common international terminology that among them task forces from the international water association (IWA) recently produced a standard approach for water balance calculation with a definition of all terms involved as indicated in table 2.3 below.

Table 2.3: IWA standard international water balance and terminology

System input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption (including water exported)	Revenue water
			Billed Un-metered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non- Revenue Water (NRW)
			Unbilled Un-metered Consumption	
	Water Losses	Apparent Losses	Unauthorized Consumption	
			Metering Inaccuracies	
		Real Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility Storage Tanks	
	Leakage on Service Connections up to point of Customer Metering			

Source: IWA (2000)

N.B: All quantities in m³/year

Water utilities around the world have always established water balances but unfortunately a wide diversity of formats and definition is used, often with in the same country so it was (and still is) virtually impossible to compare UFW, NRW leakage or water losses of different utility. Being aware of the problem of different water balance formats and methods, IWA established standard water balance as shown in table 1 above. According to IWA the above abbreviated terminologies are defined as below:

- System input volume is the annual volume input to that part of the water supply system

- Authorized consumption is the annual volume of metered and/or non metered water taken by registered customers, the water supplier and other who are explicitly or implicitly authorized to do so. It includes water exported, and leaks and overflows 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 systems in put volume and authorize consumption, and consist of apparent losses and real losses.
- Apparent losses consist of unauthorized consumption and all types of metering in accuracies
- Real losses are the annual volumes lost through all types of leaks, bursts and over flows on mains service reservoirs and service connection up to the point customer metering.

2.5.2.1 The Infrastructure Leakage Index (ILI)

The ILI is a relatively new, but very useful performance indicator, which is included in the International Water Association “Best Practice” as a Performance Indicator for Operational Management of Real Losses (Alegre et al. 2000). The ILI is a dimensionless ratio between the Current Annual Real Losses (CARL) and the Unavoidable Annual Real Losses (UARL) for a given system.

$$ILI = CARL/UARL \quad (2.2)$$

Figure 2.2 depicts the 4 methods to control the Current Annual Real Losses and the fact that every distribution network has a certain amount of Unavoidable Annual Real Losses.

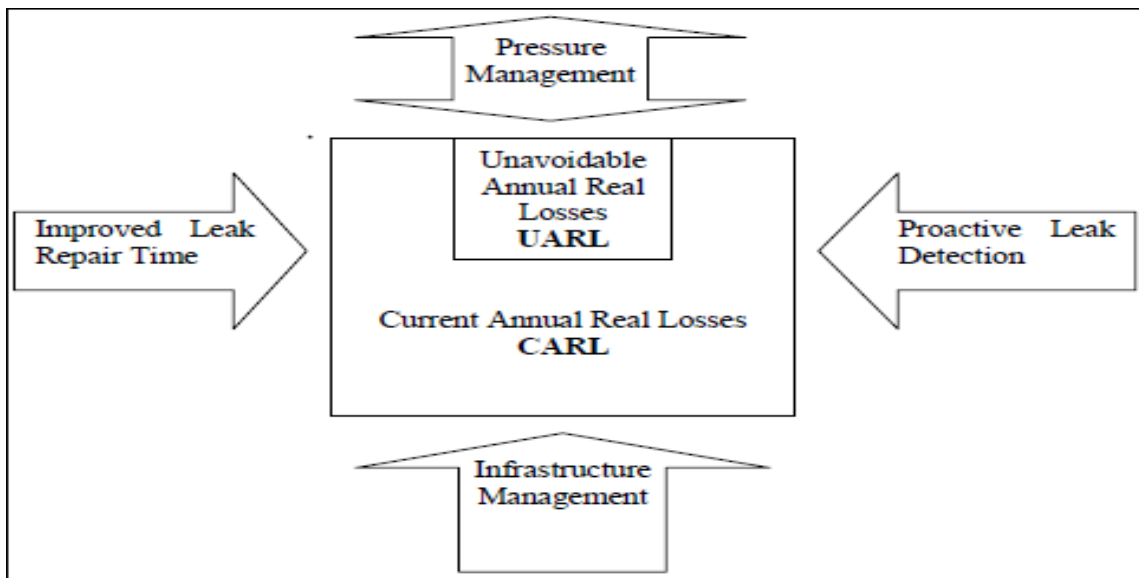


Figure 2.2: The UARL and the four basic methods of managing real losses

Source: Adapted from IWA WLTF

It is a well-known fact among leakage practitioners that real losses cannot be eliminated completely, and even in newly commissioned distribution networks, there is a minimum level of leakage. The volume of Unavoidable Annual Real Losses (UARL) - the lowest technically achievable annual Real Losses for a well-maintained and well-managed system at the current pressure – is represented by the smaller inner rectangle. The larger rectangle represents the Current Annual Real Losses (CARL) and the ratio between the large rectangle and the small rectangle represents the ILI. Equations for calculating UARL for individual systems were developed and tested by the IWA Water Losses Task Force (Lambert et al. 1999), allowing for:

- Background leakage – small leaks with flow rates too low for sonic detection if nonvisible
- Current Annual Real Losses CARL
- Unavoidable Annual Real Losses UARL
- Pressure Management Improved Leak Repair Time Proactive Leak Detection Infrastructure Management
- Reported leaks and breaks – based on frequencies, typical flow rates, target average durations
- Unreported leaks and breaks – based on frequencies, typical flow rates, target average durations
- Pressure: leakage rate relationships (a linear relationship being assumed for most large systems)

The equation used for calculating UARL is based on clearly stated auditable assumptions for background losses, been converted to a format using pre-defined pressure for a practical use as follow;

$$\text{UARL (liters/day)} = (18 * L_m + 0.8 * N_c + 25 * L_p) * P \quad (2.3)$$

Where L_m = mains length (km), N_c = number of service connections, L_p = total length of private pipe, property boundary to customer meter (km); and P = average pressure (m)

‘The ratio of the CAPL to UARL, or the ILI, is a measure of how well the utility implements the infrastructure management functions. Although a well-managed system can have an ILI of 1.0 (CAPL = UARL), the utility may not necessarily aim for this target, since the ILI is a purely technical performance indicator and does not take economic considerations into account’ (Farley, et al., 2008).

2.6 Pressure and leakage

The efficiency of a distribution system can be judged on the basis of the pressure available in the system for a specific rate of flow. Pressures should be great enough to adequately meet consumer needs. At the same time they should not be excessive and as pressure increases, leakage increases and money is then spent to transport and process a product that is wasted. Utilities are always expected to

provide adequate and safe drinking water with sufficient pressure at all delivery points. Pressures at consumers yard connections have to be as close to the minimum level as possible, though this is supposed to be determined by local authorities. The minimum pressure at a customer's connection is in the order of 15 meters while the maximum is as high as 40 meters; pressure range in excess of 60 to 70 meters will damage house installations such as boilers, float valves, taps, gaskets inside the fittings, etc. Pressure variation in a distribution network is caused, amongst others, by changes of demand of the users. Frequent starts and stops of pumps, closure and opening of control valves that induce water hammer are also some of the causes to be mentioned for pipe breakage and water loss (Lambert et al., 1998).

The pressure will be low during daytime with increase of demand and high during night hours when the demand is low. There is an excess pressure build-up in a network when demand drops especially during the night. Obviously, there is the need to cut down this unduly excessive pressure in order to avoid the bursting of pipes or reduce the amount of leakage. Variations of pressure may cause frequent pipe bursts or damages. Studies shows on the effect of high pressure on losses, particularly leakage from pipes, have indicated that leakage is almost proportional to the service pressure. The following methods can be envisaged to achieve the cutting down of the excessive pressure:- Adjust the speed of pumps to maintain reasonably constant pressures in the distribution network for areas supplied directly by pumps, Install a pressure-reducing valve (PRV) or and Divide the system into pressure zones. (Water Aid Ethiopia, 2010).

2.7 Leakage monitoring with District Meter Area (DMA)

A flow measuring system in a water distribution system should include not only measurement of total flows from source or treatment plants, but also zone and district flows. This allows the engineer to understand and operate the distribution system in smaller areas, and allows more precise demand prediction, leakage management and control to take place. The measurement system must therefore be hierarchical at a number of levels, beginning at production measurement, via zone and district measurement and ending at the customer's meter.

The technique of leakage monitoring is considered to be the major contributor to cost-effective and efficient leakage management. It is a methodology which can be applied to all distribution networks. Even in systems with supply deficiencies leakage monitoring zones can be introduced gradually. One zone at a time is created and leaks detected and repaired, before moving on to create the next zone.

This systematic approach gradually improves the hydraulic characteristics of the network and improves supply.

Leakage monitoring requires the installation of flow meters at strategic points throughout the distribution system, each meter recording flows into a discrete district which has a defined and permanent boundary. Such a district is called a district meter area and the concept of design and operation of DMA has been detailed in elsewhere (Farley and Trow, 2003).

The design of a leakage monitoring system has two aims:

1. To divide the distribution network into a number of zones or DMAs, each with a defined and permanent boundary, so that night flows into each district can be regularly monitored, enabling the presence of unreported bursts and leakage to be identified and located.
2. To manage pressure in each district or group of districts so that the network is operated at the optimum level of pressure. It therefore follows that a leakage monitoring system will comprise a number of districts where flow is measured by permanently installed flow meters. In some cases the flow meter installation will incorporate a pressure reducing valve.

2.8 Pressure management through distribution system

Pressure management can be defined as the practice to manage system pressures to an optimum level of service ensuring sufficient and efficient supply to legal uses and consumers, while eliminating or reducing pressure transients and variations, faulty level controls and reducing unnecessary pressures, all of which cause the distribution system to leak and break unnecessarily. There are many different tools that can be used when implementing pressure management, including pump controls, altitude controls and sustaining valves [Lambert et al., 2006]. It was reported that many water utilities introduced pressure management to their water distribution systems. In the most cases, large reductions in a new break frequency can be achieved over a wide range of pressures. In Australia, Canada, German and Italy, ongoing monitoring shows that the reductions in break frequency have been sustained for over five years to date by implementing pressure management procedure [Lambert et al., 2006]. On the other hand, the rapid reduction in new break frequency following pressure management is immediately evident for water loss management. Some of the pressure management benefits reported by many different utilities include:

- Reduction in annual repair costs
- Reduction of the repair backlog, shorter run times for bursts
- Fewer emergency repairs, more planned work

- Reduced inconvenience to customers

Calculations of the economic benefit of pressure management have been based on the predicted reduction in flow rates of existing leaks and the value of the water thus saved. If management of excess pressure can also regularly achieve reduction in numbers of breaks of between 28% and 80% per year [Lambert et al., 2006], the annual savings in repair costs will usually be far greater than the value of the water saved.

Replacement of mains and services, the most expensive aspect of water distribution system management, is normally initiated by break frequencies that are considered to be excessive. Most water utilities consider break frequency to be a factor outside their control, and something that can only be remedied by expensive replacement of mains and services. However, if pressure management can reduce break frequencies and extend the working life of parts of the distribution infrastructure by even a few years, the economic benefits would generally be even greater than the short term reduction in repair costs.

2.9 Water supply distribution network analysis

2.9.1 History of hydraulic modelling

The use of mathematical methods to calculate flows through a complex pipe network was first proposed by Hardy Cross. For utilizing the Hardy Cross methodology, improved solution methods were developed with the advent of computers and computer based modelling. Initially hydraulic models were simulating flows and pressures in a distribution system under steady state conditions assuming all demands and operations remained constant, but since demands and flows vary over the course of a day, Extended Period Simulation Models which can simulate distribution systems behavior under time-varying conditions were developed (EPA, 2005). Steady state simulations were advanced to EPS using the technique developed by Rao and Bree in the late 1970's (Laura Baumberger et al., 2007).

2.9.2 Principle of network hydraulics

In the network of inter connected hydraulic elements, every element is influenced by each of its neighbors; the entire system in such a way that the condition of one element must be consistent with condition of all other element. Two basic equations that govern in water CAD modeling network of these inter connections (Bentley Water CAD/GEMs, 2008)

- ❖ Conservation of mass or continuity principle
- ❖ Conservation energy or energy principle

2.9.2.1 Conservation of mass

For Steady incompressible flow

Net flow into the junction = Use at the junction

Mass in = Mass out

$$\sum Q_{in} \Delta t = \sum (Q_{out} + \Delta V_s) \quad (2.4)$$

Where: Q_{IN} = Total flow into the node (m^3/s , cfs)

Q_{OUT} = Total demand at the node (m^3/s , cfs) and ΔV_s = Change in storage volume (m^3)

2.9.2.2 Conservation of energy

The energy equation is known as Bernoulli's equation (Amdework, 2012). It consists of the pressure head, elevation head, and velocity head. There may be also energy added to the system (such as by a pump), and energy removed from the system due to friction. The changes in energy are referred to as head gains and head loss.

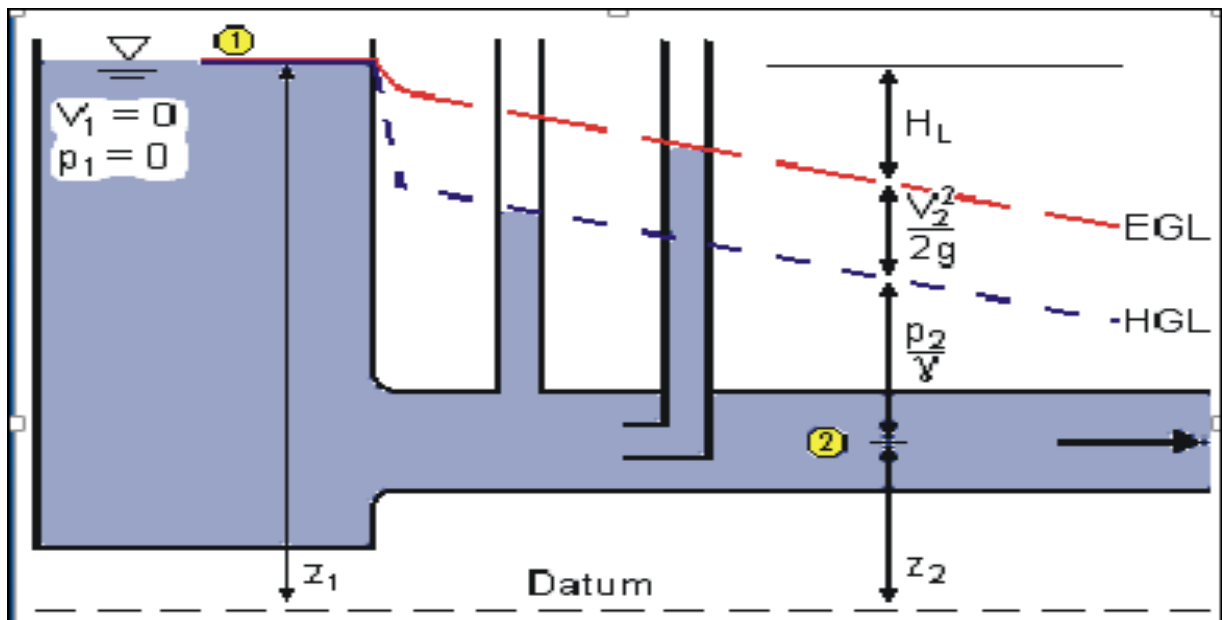


Figure 2.3: Forms of energy in water pipes

Source: (Bentley Water CAD/GEMs, 2008)

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g} + h_L \quad (2.5)$$

Where p = the pressure ($\frac{lb}{ft^2}$ or $\frac{N}{m^2}$)

γ = the specific weight of fluid ($\frac{lb}{ft^3}$ or $\frac{N}{m^3}$)

z = the elevation at the centroid (ft or m)

v = the fluid velocity (ft/s or m/s)

g = Gravitational acceleration ($\frac{ft}{s^2}$ or $\frac{m}{s^2}$)

h_L = the combined head loss (ft or m)

There are three forms of energy

- Pressure head = $\frac{p}{\gamma}$
- velocity head = $\frac{v^2}{2g}$
- elevation head = z

2.10 Water supply distribution element system

2.10.1 Distribution reservoir

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

2.10.2 Storage tanks

Storage Tanks are artificial structures that store water and provide water to the system when needed. Equalizing and emergency storage are the two basic task of storage tanks. In peak demand hours, required water may not be satisfied by pumps only. At this situation, extra water is taken from storage tank and water distribution network is equilibrated by storage tank. Moreover, in low demand hours when the water consumptions of consumers are almost zero, amount of pumped water is higher than system demand and extra water coming from pumps are stored at storage tank and equilibrium of water distribution system is satisfied again. This equilibrium purpose of storage tank is called as equalizing storage. In addition, storage tanks help water utility to easily manage pressure distribution by preventing pressure fluctuations. Emergency storage ability of storage tanks provide required water to perform fire-fighting operations or maintenance operations. For instance, if the pump of distribution network is turned off due to power cut, distribution network continues to

serve to the customers by using water stored in the storage tank till the end of power outages (Al-Rayess, 2015).

2.10.3 Pipes

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

2.10.4 Valves

In a water supply system, valves are the major component to control the flow of water. By operating the valve the flow can be controlled in different ways. Completely preventing water flow, adjusting the amount of water flow, directing flow to different paths and reducing flowing water pressure are some of capabilities of valves in water supply system. Valves may be operated manually, either by a handle, lever or wheel. Valves may also be operated automatically by electronic devices and may be operated remotely (Newbold, 2009).

2.10.5 Fire hydrants

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

2.10.6 Pumps

A pump is a device used to move water by mechanical action. An electrical motor is used to convert electrical energy to mechanical energy and this mechanical energy is transferred to the pump with the help of driveshaft. The transferred mechanical energy is used to overcome friction losses of pipes, minor losses of system components and also to provide pressurized flow at needed points (Zyoud, 2003). As mentioned in introduction part energy cost of water supply system is directly related to pumps. Therefore, in the design process of water supply network, pumps are carefully selected depending on design requirements. In addition, operation process of pump station should be diligently maintained during the lifetime of pump with respect to dynamically changing water supply systems.

Pumps are divided into three type categories; centrifugal pumps, rotary pumps and reciprocating pumps. In this study, types of all pumps used in case study are centrifugal pumps.

2.11 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).

2.12 Water demand and demand Factor

2.12.1 Water demand

Consumption or water demand is that part of the water leaving the system at customers’ faucet, leaky mains or open hydrants. This demand is the driving force behind the hydraulic dynamics in the distribution system (Amdewerk, 2012). It is possible to evenly distribute the overall demand data to each node starting from the bottom from the customers’ billing records or from the top the treatment plant production data.

Most water distribution system soft wares use geocoded billing meter records, production data, census tract, land use zoning, traffic analysis, demand density information and meter routes information for spatially allocate the demands and the spatial analysis capability of GIS soft wares is used by these Water distribution hydraulic models (Laura Baumberger et al., 2007).

We can estimate demands by counting the number of structures using representative consumptions per structure, using meter readings and assigning each meter to nodes and land uses, then applying a global factor to account the UFW so that total usage corresponds to total consumption. For effective EPS, developing temporal patterns using the best available information from continuous meter reading or from literature, is required. To assign baseline demands spatially, information is acquired from water utilities billing records, but this assignment should include customer classes such as residential, industrial, commercial users and diurnal varying demands should be developed for each major customer class or for each geographic zones with in a service area (Wood, 1980).

Models require base line demands and information on how demands change over time for extended period simulation. Average-daily demand, maximum-daily demand and peak-hour demands are demand events which are frequently considered.

Determining the amount of water being used, where it is being used and its variation with time is key to modelling and it shows the overall success of the modeling; because water demand is the driving force behind the operation of water supply distribution systems.

Demand determination is not straight forward. Billing and production records can be directly collected from utilities, but these data are not in the form that can be directly entered in to the model. After collecting these data, consumption rates will be established by studying the past, present and future projected usages. Then the water use is spatially distributed as demands or loads, assigned to model nodes; it is called loading the model.

The demands can be customer demand, UFW or fire flow demands. Customer demand and UFW together forms the base-line demand. Base-line demand is usually the average-daily demand in the current year from which other demand distributions are built. Simple unit loading method is the most common method for allocating base-line demands.

2.12.2 Demand multiplying factors

Peaking factors are multiplication factors which can be applied on some consumption conditions, especially for predicted consumption conditions, for example future maximum demand condition. The peaking factors from average-daily demand to maximum-daily demand and from maximum-daily

demand to peak-hour demand can be determined from the ratios maximum-daily demand to average-daily demand and peak-hour demand to maximum-daily demand, respectively. Determining the system-wide peaking factor is so simple if good records of production and tank levels are available, but determining peaking factors for each individual node is so difficult; because each individual node do not necessarily follow the same demand pattern as the whole system (Bowen, 1993). According to FDRE, Ministry of Water Resource; the proposed peak factor and patterns for demand multiplying factor based on population category is tabulated in the table below.

Table 2.4: Peak Hourly multiplying factor based on population number

Population	Peak hour factor	Maximum day factor
0 – 20,000	2	2
20,010 - 50,000	1.9	1.9
50,001 and above	1.8	1.8

Source: Design Manual of MoWR (2006)

3. RESEARCH METHODOLOGY

3.1 Descriptions of the study area

Location: Debre Brehan Town is located in North Shoa Zone of Amhara region, about 130km North East of Addis Ababa on the paved highway to Dessie. The town has latitude of $09^{\circ}41'N$ and $39^{\circ}32'E$ longitude and Altitude ranges from 2750 to 2871m a.s.l from the elevation it belongs to dega climatic zone (Ermias, 2007). It was an early capital of Ethiopia and afterwards, with Ankober and Angolalla, was one of the capital of the kingdom of Shoa. The town has a total area of 14.71km^2 (5.68. sq. mill).

Population: According to CSA (2012), population of the town was 160,408 with the density of $11,000/\text{km}^2$ and average annual growth rate of 4.4%. The town is administratively divided into nine administrative units namely; 01, 02, 03, 04, 05, 06, 07, 08 and 09 kebeles.

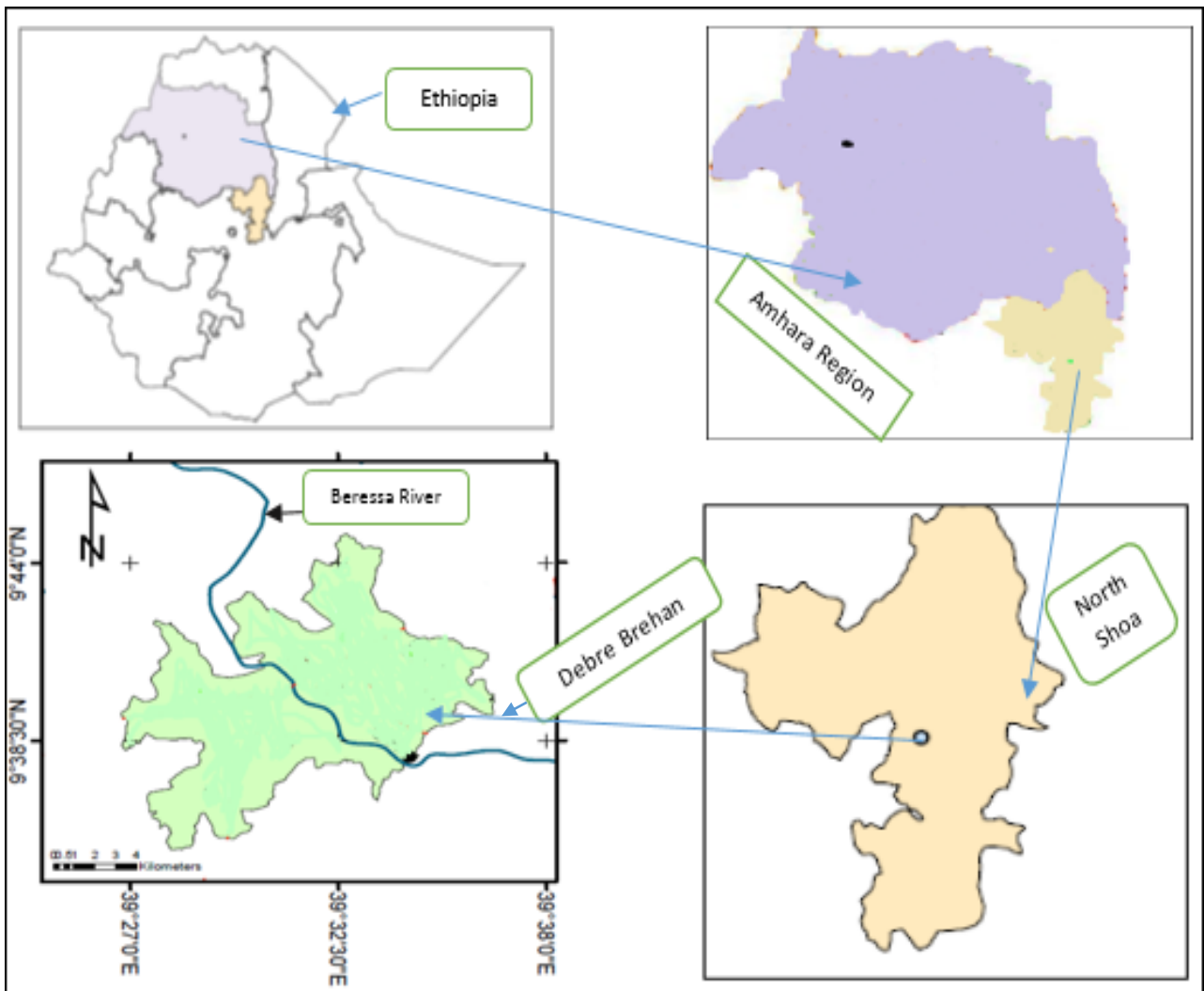


Figure 3.1: location map of Debre Brehan Town

3.2 Research process

The water supply coverage of the town was first evaluated before analyzing the water loss. In evaluating the water supply coverage the focus will be on the volume of consumption and level of water connection as these are highly related to the issue of water loss. After evaluating the distribution of water supply coverage in the town, the water loss from the distribution system of the utility was analyzed.

3.3 Study design

Interview: To secure additional information, unstructured interview question were conducted.

Observation: Site observation was conducted to analyze the water supply coverage and water loss from the distribution system. Information was collected from town water supply and sewerage office experts, office administrative, local communities and concerning sectors.

3.4 Sampling size and procedures

Since a complete listing of household in the survey area was not available, clustered sampling used for this study. Clustering of Kebele was based on population size and geographical location of the residents.

3.4.1 Sampling procedure

Target Population: The definition of targeting population would be in line with the objectives of water supply coverage and causes of leakage in the distribution system. **Specific Sampling unit:** All parties become a sampling unit and all contractors engage in water supply construction projects become the sampling elements.

Specific sampling frame: The sampling would be design from the list of participants in water supplies.

3.5 Study variables

The study variables asses in this research were both independent and dependent variables.

Independent variables: independent variables were more related with specific objectives. However, each specific objective was affecting one another. Different problems occurs before and during water supply and distribution stages under construction.

- Joints of pipe
- Sizes of pipe

Dependent variable: dependent variables, which observed and measured to determine the effective of the independent variables, which was directly, related to the general objectives.

- Per capita demand
- Water losses

3.6 Data collection process

The study needs mainly both primary and secondary data which collected by using different data gathering method.

3.6.1 Primary data collection:

The data were collected on field survey by observation, collecting, and measuring. Pressure gauge was used to measure pressure at selected point and GPS survey were used in locating the latitude and longitude of the system. And also by using digital camera the photo view of the necessary structures were collected.

3.6.1.1 Pressure measurement

Pressures are measured throughout the water distribution system to monitor the level of service and to collect data for use in model calibration. Pressure readings are commonly taken at fire hydrants also at hose bibs, and home faucets (Bentley, 2008). For this study Pressure measurement was taken at different time during low demand time and peak demand time while at different place in the distribution system at selected home faucet which are located near to representative the sample nodes. At location where pressure measurement were conducted, elevation readings were also taken. Based on investigation survey ten representative sampling sites were selected to determine the average operating pressure for the calculation of unavoidable annual real loss and leakage in the distribution system each zone is vital for model calibration.

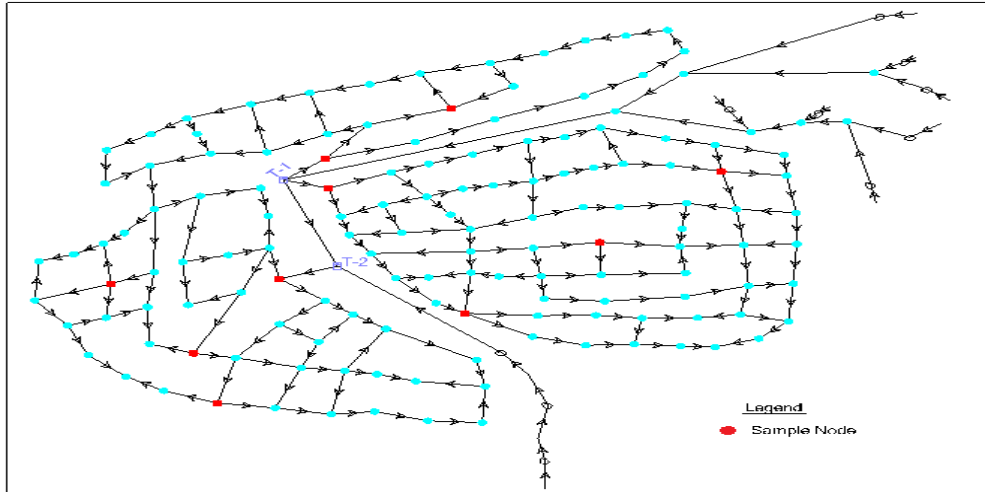


Figure 3.2: Sampling location in the distribution system.

3.6.2 Secondary data collection:

The data were collected from different concerned organization and agencies; such data includes: production and variation of water demand. Billing on water consumption, Water distribution network data, such as: Pipe information (diameter, length, type of pipe), Valves diameter and head, Tank information (base, initial, minimum and maximum elevation and diameter), Pump head (design and flow head). And Source location and head.

3.6.2.1 The town water supply networks

The entire town water supply network including their attribute like the length, diameter, material types, pumps characteristics and storage tank information has been collected from the town water supply service office. The collected pipe network mainly comprises of pipes which having diameter (50-400) mm that covers the major part of the town. Extension networks are also included in the existing network during the site observation. The length of the entire network was summed up according to their diameter of further determination of unavoidable annual real loss.

3.6.2.2 Water production

The town drinking water supply has a long history back to 1935 during Italian invasion of Ethiopia. The Italian forces constructed a pipe water distribution system using “Atse Zeriayaqob” spring as a water source. Hence the town has 75 years of history of piped drinking water distribution. In 1977 the Debre Brehan Water Supply and Sewerage Service (DBWSSS) office was established as an independent government office (DBWSS, 2016).

DBWSSS office is the one which is responsible to give drinking water and sanitation service for the people of the town. Debre Brehan, like any other towns in developing countries suffers from clean

water source, distribution and sanitation problem. DBWSSS office in order to supply sufficient drinking water to the public should have source of water that cover the demand. The office has been using River Beressa as water source to distribute drinking water to public. The water which had been distributed to the public previously had extremely high problems both in quantity and quality. In 2008 the new water system in the town was developed with the fund obtained from France Development Aid (AFD) and an agreement made with Water Resource Bureau of Amhara National State (WRBANS). As a result of this ten boreholes were dug as water source and two reservoirs with all civil works and distribution system constructed. The wells are about 70-125m depth are known to exist at Debre Brehan. Seven wells are found at south-east of the town commonly known as Dalecha well field with a total discharging capacity of 52 l/s and three wells are found in the south direction of the town around Beressa area with a total discharging capacity of 45 l/s. Therefore, the total discharge of the town is 97 l/s. On the other hand Beressa River is still another source of water used for different water needs in the town (DBWSS, 2016).

Table 3.1: Description of water source in Debre Brehan (DBWSS, 2016)

Name of Bore Hole	Depth of Well (m)	Diameter of Well (inch)	Pumping position (m)	Rate of Pump (l/s)	Daily Working Time (hr)	Water yield		
						m^3/day	$m^3/year$	
Delecha Bore Hole	DABH1	108	8	83	7	22	554	202,356
	DABH2	95	8	66	8	22	634	231,264
	DABH4	125	8	74	5	18	324	118,260
	DABH6	107	8	86	10	22	792	289,080
	DABH7	90	8	59	12	22	950	346,896
	EX BH2	70	6	60	5	18	324	118,260
	EX BH1	70	6	60	5	18	324	118,260
Beressa Bore Hole	BE BH1	99	8	56	15	22	1188	433,620
	BE BH2	92	8	39	15	18	972	354,780
	BE BH3	90	8	70	15	18	972	354,780
SUM TOTAL				97			7,034	2,567,556

3.6.2.3 Town water reservoirs

Table 3.2: The two-water distribution reservoir in Debre-Brehan Town
(DBWSS, 2016)

ID	Supply Zone /kebeles/	Elevation (m)	Capacity (m ³)	Remark
R ₁	01,02,03,06,07 & 08	2865	2000	New
R ₂	04,05, & 09	2837	1000	New

There are two concrete reservoirs in the distribution system located at two places. The one circular concrete reservoirs(R₁) found around Selase church at an elevation of 2865m.a.s.l. The capacity of reservoir (R₁) is 2000m³ and its supply zones are 01, 02, 03, 06, 07 and 08 kebeles. And the second circular concrete reservoir (R₂) is found around Maremiabet it has an elevation of 2837m.a.s.l with the capacity of 1000m³. Its supply zones are 04, 05 and 09 kebeles.

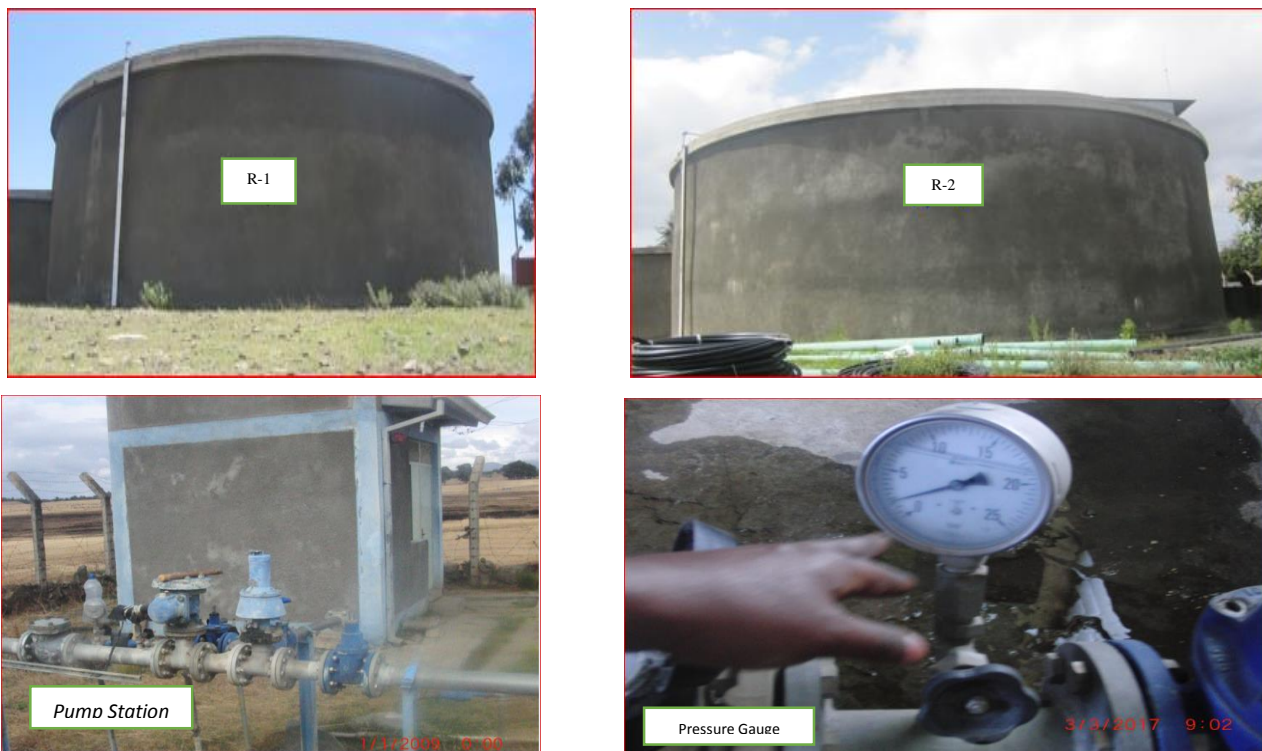


Figure 3.3: Debre-Brehan Town water Supply Reservoirs and perssure gauges.

Source: photo taken during filed observation

3.6.2.4 Population distribution by mode service

According to the town water service office reports, there are four major modes of services for domestic water consumers of Debre Brehan town. These are;

1. House Connections (HC)
2. Yard Connections Shared (YCS)
3. Yard Connections Private (YCP) and
4. Public Fountains (PF)

Table 3.3: Debre Brehan town domestic water supply coverage by mode service

Mode of Services	Town of Debre Brehan		
	Service Connections	Served Population	Coverage (%)
HC	5,541	68,688	35.91
YCS	2,688	33,320	17.42
YCP	1,710	21,193	11.08
PF	4,343	53,844	28.15
Total	14,281	177,046	92.56

Source: DBWSS (2016)

Table.3.4 Domestic water demand for different categories of consumer

No	Connection Type	Minimum (l/c/day)	Maximum (l/c/day)
1	House Connection	50	70
2	Yard Connection	25	30
3	Yard Connection shared	30	40
4	Public fountain	30	40

Source .Design criteria of MoWR (2006)

3.5 Method of analysis

3.5.1 Water supply coverage analysis

The water supply coverage of the town has been evaluated based on the average per capita consumption and level of connection per family. The average per capita consumption has been derived from the yearly consumption that was aggregated from all type of customer water meters. Beside to the average per capita water consumption, the distribution of number of domestic connection per family has been also evaluated. Statistical analysis was used to evaluate the supply coverage for the entire town.

3.5.1.1 Average daily per capital consumption

The volume of water consumed for domestic purpose has been aggregated to all 9 kebeles of the town so as to analyses the distribution of the water supply coverage among different localities. The annual consumption data has been converted to average daily per capita consumption using the number of population. The average daily per capita consumption of each kebele was derived using the following expressions:

$$\text{Per Capita Consumption} \left(\frac{1}{p/d} \right) = \frac{\text{yearly consumption (m}^3\text{)} \times 1000 \frac{1}{\text{m}^3}}{\text{number population in the kebele} \times 365} \quad (3.1)$$

$$\% \text{ of water coverage} = \frac{\text{Water beneficiary population}}{\text{Total population}} * 100 \quad (3.2)$$

3.5.1.2 Level of connection per family

In order to compare the distribution of the water connection among the different kebele, the total numbers of connections per kebele are converted to connection per family using the population data of each kebele by the following expression.

$$\text{Conection Per family} = \frac{\text{Total number of conection in the keble}}{\text{number of population in the keble/average family size.}} \quad (3.3)$$

3.5.2 Water loss analysis

The total annual water produced and distributed to the distribution system and the water billed that was collected from the individual customer meter readings were used to quantify the total water loss for the Debre Brehan town.

$$\% \text{ of water loss} = \left(\frac{\text{Total water production} - \text{Total billed data}}{\text{Total production}} \right) * 100\% \quad (3.4)$$

Even though real water losses were obtained by Greeley equations in manually to quantify the leak in circular holes for the transmission, distribution, and connection pipes lines for this study only leak through transmission and distribution line is calculated because there is limitation of such data in the study are by using unpublished report from the office it can be calculated by Greeley's formula as:

$$Q = \left[\frac{43,767}{1440} \right] * A * \sqrt{P} \quad (3.5)$$

Where, Q = flow in gallons per minute

A= the cross sectional area of the leak in square inches

P= the pressure in pounds per square inch (AWWA California Nevada section, 1992),

Unavoidable Annual Real Losses (UARL)

Considerable work was undertaken to assess the minimum level of leakage for any system (Lambert et al 1999) and after careful analysis a relatively simple and straightforward equation was developed as follow.

$$\text{UARL (liters/day)} = 18 \times L_m + 0.8 \times N_C + 25 \times L_P \times P \quad (3.6)$$

Where L_m = Mains length (km) N_C = number of service connection L_P = total length of private pie, property boundary to customer meter (km) P = average pressure (m).

3.5.3 Distribution system analysis

3.5.3.1 Hydraulic modeling software

The hydraulic modeling software Water CAD simulation was carried out for the purpose of pressure regime for customers demand, velocity, and head loss and overall systematically studding and better understand network operation.

The use of the above software is recommended that the up to date Water CAD software for an unlimited number of pipes is appropriate for the development of the skeletal and all mains models of Debre-Brehan water supply network.

The level of skeletonization depends on the purpose of the study. This study is intended to be used for general purpose, especially for improving the operation, management and controlling water loss of Debre Brehan town water supply distribution system. So the skeletonization technique will not affect the purpose of the study as long as components with significant impacts on the whole system are included in the model. It is possible to identify segments with significant impact on the performance of the network by undertaking criticality analysis using water GEMS software, the whole AutoCAD network pipes were imported as they are on the auto CAD drawing with slight addition for missing pipes and deletion of some mis-placed pipes. But by obeying the skeletonization rules,

significant changes were made on the AutoCAD nodes to create the model nodes for modelling the distribution network. The level of skeletonization is also still within the moderate range.

To perform the model building process, data for modeling the system which were missed during the data collection, especially the elevations of demand nodes were generated using hard copy design document in addition to AutoCAD layout to import to water GEMS software.

After building the distribution layout using the combination of Google earth, AutoCAD and water GEMS software, all the collected data and generated input data were entered in to the water GEMS model and running the model was performed to test the reasonableness of the simulated parameters with in the network

3.5.3.2 Population forecasting

Different population forecasting methods are in fact available and can be used for population projection. But their result varies from one method to another. Preference of the method appropriate for particular town needs to consider overall current situations of the targeted town.

For fast growing town, where relatively high economic activity is observed and at the same time continuous expansion of town due to various reasons is experienced, exponential method population forecasting is preferably used.

Exponential population forecasting method is expressed as follows;

$$P_n = P_o e^{rn} \quad (3.7)$$

Where, P_n = population at year n

P_o = base year population

e = constant e, the base of natural logarithm

r = population growth rate

n = projection year

3.5.3.3 Nodal base demand Calculation

To allocation Base Demand each node in Debre Brehan water supply distribution network the following steps were followed.

- **Step-I:** Estimating the current designed (2016) Population size for the entire town using Exponential Population forecasting method the detail is shown on Table 4.9 and Table 4.10 at the Discussion part this paper.

- **Step-II:** Number of house for each node was identified for this the Image of the town was Overlapped with the distribution network of supply system and the number houses were Counted from the image for each node by considering the real situation of the town.

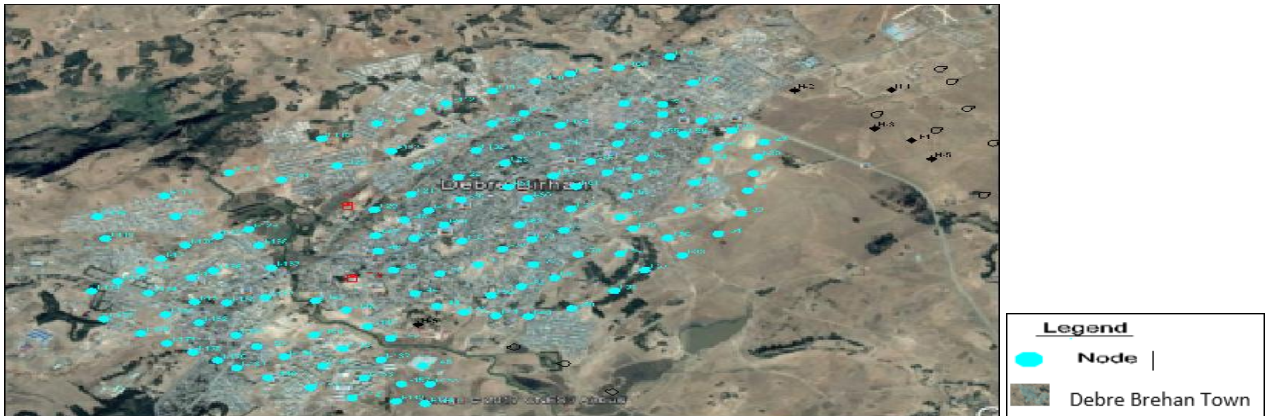


Figure 3.4: Overlap of Image of town and Node of distribution system

- **Step-III:** Determining the number people in each house in order to verify the people at each node in the distribution system. From the town population estimation report the average family was four therefore by multiplying the number house around each node by this average family size total population for each node could gained. The overall calculation is assigned on the *Appendix-I*.
- **Step-IV:** Determining Current Average Day Demand (ADD) of the Town

$$\text{ADD} = \text{per capita consumption} * \text{Total population of the town}$$

- **Step-V:** Determining Base water demand for each node

$$\text{BWD} = \frac{\text{Population using the node}}{\text{Total population of the town}} * \text{ADD} \quad (3.8)$$

3.5.3.4 Model analysis

Analysis of the model of existing system has been made by running the model at current year daily average, at peaking and temporal variations of demand with different scenarios.

Steady state Analysis: The model has been performed in steady state run for the average daily demand, which is the demand at every node not changing throughout 24 hours of a day. The software simulates Steady-State hydraulic calculation based on mass and energy conservation equations principle.

Extended Period Simulation: The system conditions have been computed over twenty-four hours with a specified time increment of one hour and starting model run time at 6:00 A.M. The software simulates non steady State hydraulic calculation based on mass and energy conservation principle.

The model can be simulated for every one-hour time setup in the day and night part of time for twenty-four hour duration. And for the analysis the peak and minimum hours, demand has been simulated to identify the current problems of the system.

3.5.3.5 Model calibration and validation

Field data collection is the first and key steps to provide insight in to the performance of the system and model calibration (Walski et al., 2001). Therefore, for model calibration and validation effort pressure data were collected from field visits and for this study pipe roughness was taken as model parameter to be adjusted. According to Pressure Criteria (Bentley Water CAD/GEMs, 2008), Model calibration and validation were undertaken based on the following Acceptable levels of calibration: - 85% of field test measurements should be within ± 0.5 m or $\pm 5\%$ of the maximum head loss across the system, whichever is greater, 95% of field test measurements should be within ± 0.75 m or $\pm 7.5\%$ of the maximum head loss across the system, whichever is greater. And 100% of field test measurements should be within ± 2 m or $\pm 15\%$ of the maximum head loss across the system, whichever is greater.

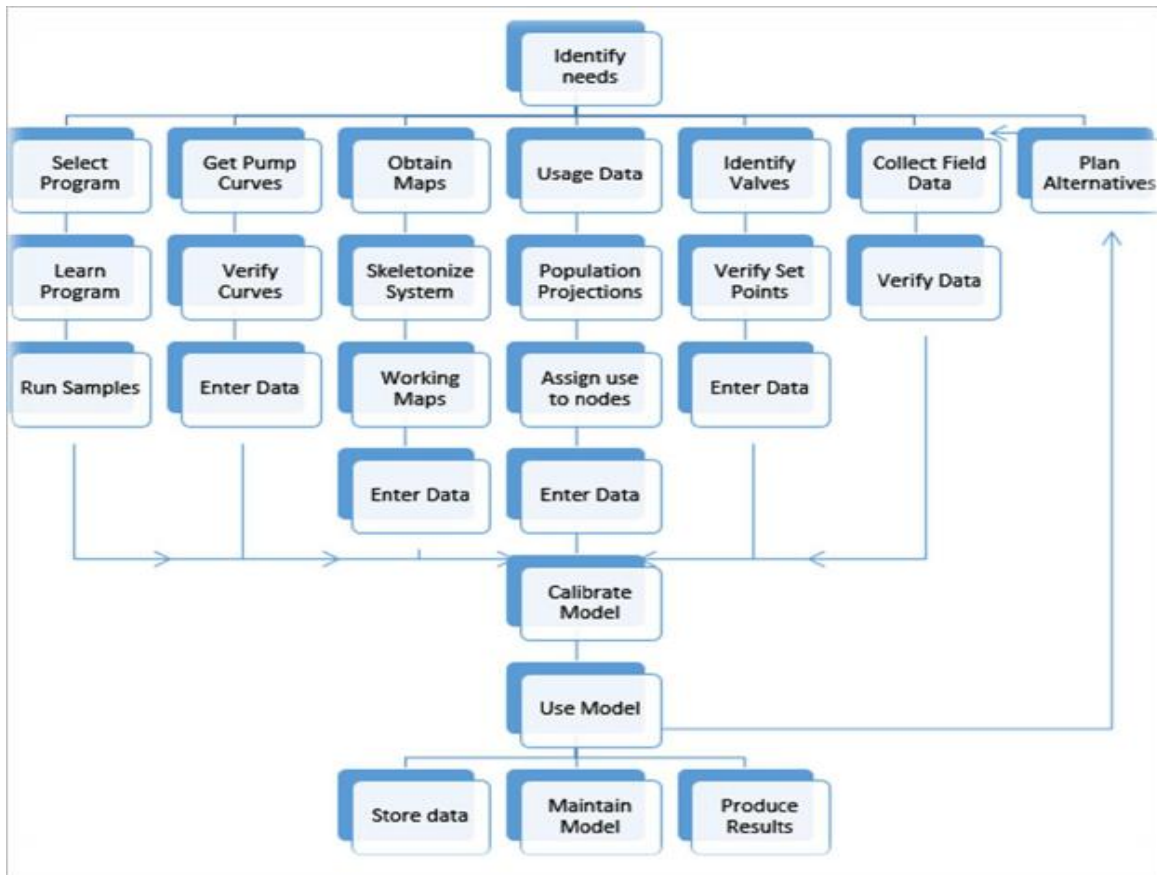


Figure 3.5: flow chart of modeling process (Walski, 2003)

4. RESULT AND DISCUSSIONS

4.1 Water supply coverage and distribution

4.1.1 Domestic water supply coverage

The water supply coverage of the town were evaluated based on the average per capital consumption and level of connection per family.

4.1.2 Average daily per capital consumption

The amount of water consumed for domestic purpose was analyzed to all kebele of the town so as to know the distribution of the water coverage among different part of the town. Statistical analysis was used to evaluate the distribution of the supply coverage in all kebeles of the town. Evaluating the domestic water supply coverage using volume of consumption may not allow realizing the distribution comparison among the kebeles. For this reason the annual consumption data has been converted to average daily per capital consumption using the number of population. The average daily per capita consumption of each Kebele for the year 2016 was computed as follows.

$$\text{Per Capita Consumption} \left(\frac{1}{p/d} \right) = \frac{\text{yearly consumption (m}^3\text{)} \times 1000 \frac{1}{\text{m}^3}}{\text{number population in the kebele} \times 365}$$

Table 4. 1: Average daily consumption with in all Kebeles of Debre Brehan town.

Kebele	Population in each Kebele	Annual Consumption In each Kebele (m ³)	Per capita consumption (l/person/day)
01	9,491	85,235	24.61
02	28,548	235,472	22.60
03	21,933	182,305	22.77
04	29,793	258,386	23.76
05	19,886	175,156	24.13
06	24,580	211,997	23.63
07	9,531	85,995	24.72
08	23,261	168,691	19.87
09	24,254	204,144	23.06

As Table 4.1 observed that, the distribution of the water consumption varies among each Kebele. More or less the variation is observed in all Kebele; particularly Kebele 07 has relatively better average consumption while kebele 08 has lower average consumption as compared to the others. By

taking the mean consumption as shown in Table 4.1 the distribution of average domestic water supply coverage of the town is found to be 23.24 l/capital/day. This average per capita consumption is very low while compared with the country standard used for design purpose (30 to 60 l/capital/day) as described in (ADB, 1993). According to some literatures, a minimum quantity of 25 l/capita/day domestic water supply categorized as basic level of service (Wallingford HR, 2003) which is higher than the average domestic consumption of the town. According to office authority data the town has been reached 92.56% water supply coverage from the total population in the current year with including HC, YCS, YCP and PF while the remaining 7.44% population uses unsafe water from different source.

4.1.3 Level of connection per family

Level of water connection was an important element for evaluating the level of coverage. In order to compare the distribution of the water connection among different Kebele of Debre Brehan town, the total numbers of connection per Kebele were converted to connection per family using the population data of all Kebele in the town. According to the CSA (2007) and the town administrative finance and economic development, Average family size 4 was used.

$$\text{Conection Per family} = \frac{\text{Total number of conection in the keble}}{\text{number of population in the keble/average family size.}}$$

Table 4. 2: Level of connection per family of Debre Brehan town for the year 2016

Kebele	Number of population in each Kebele	Average family size	Total number of connection in each Kebele	Level of connection
01	9,491	4	910	0.38
02	28,548	4	1733	0.24
03	21,933	4	1330	0.24
04	29,793	4	2167	0.29
05	19,886	4	1060	0.21
06	24,580	4	2303	0.37
07	9,531	4	1312	0.55
08	23,261	4	1975	0.34
09	24,254	4	1491	0.25

As can be seen from the Table 4.2, some of the Kebele are found to be having relatively better level

of connection per family while compared with Kebele 07 have better value of connection per family as compared to other Kebele. Taking the average connection per family for the entire town was found 0.32. This indicates that at average more than three families or thirteen persons are sharing one connection or water tap. In other words the average in house, yard or public tap connection of the town is about 32%.

4.1.4 Average daily per capital consumption and percent coverage trend in the town

The level of water production and consumed for domestic purpose has been aggregated to all kebeles of the entire town so as to analysis the distribution of the water coverage in town.

$$\% \text{ of water coverage} = \frac{\text{Water beneficiary population}}{\text{Total population}} * 100$$

Table 4.3: Water production and consumption of Debre Brehan town (2011-2015)

Year	Total production (m ³)	Total Billed data (m ³)	Total population	Water beneficiary population	Water Production l/person/day	consumption l/person/day	% of coverage
2011	2,271,906	1,285,326	153,350	145,729	40.59	22.96	95.03
2012	2,331,036	1,364,894	160,408	150,046	39.81	23.31	93.52
2013	2,390,166	1,401,686	167,624	155,672	39.07	22.91	92.87
2014	2,449,296	1,512,253	174,465	161,886	38.46	23.75	92.79
2015	2,508,426	1,575,493	182,313	168,949	37.70	23.68	92.67
Average					39.13	23.32	93.38

Taking the mean production as shown in above the average domestic water coverage of the town is found to be 39.13 l/per/day and the consumption is 23.32 l/per/day in between the year (2011-2015). The average daily per capital production of the town was very low since from this production the average water loss between the above mentioned year was more than 40% before reach to costumer whereas the water supply coverage of the town was decreasing gradually from year to year due to floating of population who shares from the daily water proceed, in additional to the increase in the number of university and college of students, hospitals and health centers, gusts and visitors as a result of conference, establishment of hotels and industries all contributed to the water shortage of the town.

4.1.5 Evaluating of the distribution of the water supply coverage

According to (table 4.1 and 4.2), the water supply coverage of the town in terms of both Per capita consumption and level of connection was found to be low. In areas where water supply coverage is sufficient, volume of domestic water consumption is expected to be linearly related to the level connection. Areas having better level of connection are expected to consume more water as they can easily get it within their building or compound. Some areas may have better level of connection that consuming more volume of water, as the possibility of getting the water does depend on the location (Kebele 07 has better connection per family of 0.55 and also has per capita consumption of 24.72 l/c/d which is near to the minimum required value of 25 l/c/d).

4.1.6 Average demand by mode of service

Analyzing of demand by mode of service is important to identify the distribution of demand with type of connection in the town. Currently in Debre Brehan town four type of mode of service are there. The average demand is analyzed by multiplying per capita demand with the corresponding population size of each mode service based the data stated in the methodology (table 3.3 & 3.4).

Table 4.4: Analysis of average day demand

No	Connection Type	Population Size (2016)	Per Capita Demand (l/c/d)	Average Demand (l/c/d)	Average Demand (l/s)
1	House Connection	68,688	55	3,777,816.58	43.72
2	Yard Connection Privet	21,193	30	635,804.78	7.36
3	Yard Connection Shared	33,320	35	1,166,215.93	13.50
4	Public Fountain	53,844	35	1,884,556.74	21.81
	Total				86.39

As can be seen from the table 4.4, the total average demand based on mode of service is 86.39 l/s. While, according to DBWSS data the production of water from ten bore hole is 97 l/s. Among this production of water 37.40% loss before reached to the customer. Thus, the net production of the town 36.28 l/s. Therefore, there is a high gap between the current water supply and demand of the town.

4.2 Water loss analysis

One of the major challenges of water utilities is high volume of water loss in their distribution networks. If a large quantity of supplied water is lost; it is difficult to meet the required quantity to demands, and correspondingly made challenges to keep the water tariffs in the system at a reasonable

level. The total annual water produced and the water billed that was aggregated from all type of customer meter readings were used to quantify the total water loss for Debre Brehan town.

Table 4.5: Annual Water loss from the year 2011 to 2016

year	Total production (m ³)	Total Billed data (m ³)	Total water loss (m ³)	% of water loss
2011	2,271,906	1,285,326	986,580	43.43
2012	2,331,036	1,364,894	966,142	41.45
2013	2,390,166	1,401,686	988,480	41.36
2014	2,449,296	1,512,253	937,043	38.26
2015	2,508,426	1,575,493	932,933	37.19
2016	2,567,556	1,607,381	960,175	37.40

As can be seen from the table 4.5 the total annual water loss of the town is decreased from year to year because one of the factor for water loss was infrastructure expansion like road construction so, in the recent years these road construction has become phase out and completed in the town. At the end of the year 2016 the annual water produced and distributed to the system within specified year was 2,567,556 cubic meters and the total billed water was 1,607,381 cubic meters therefore; the annual water loss as derived using this expression was 960,175 cubic meters which accounted to 37.40% of the total production at this year loss begin to increase due to age of pipe and water meter. Annual water loss of the town is showed in the figure blow.

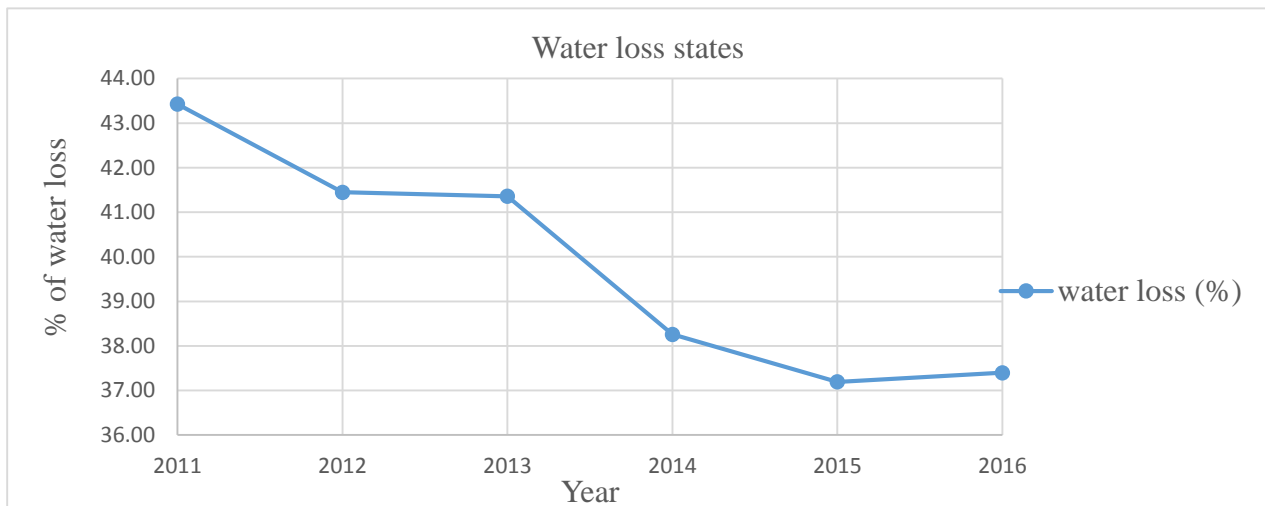


Figure 4.1: Annual loss of the town

4.2.1 Water loss as per number of connection

Water loss expressed as a percentage could be an appropriate means to show the extent of the loss within a given environment, but it is not a good indicator for comparing the loss from one area to another. According to some literature comparison of water loss between different areas is recommended to be done using the water loss per service connection per day. Taking the total number of connection in the town as 17,729 the water loss per connection for the similar duration was derived as,

$$\text{Loss per connection} = (\text{Total water loss} * 1000 \frac{1}{\text{m}^3}) / (\text{Total number of connection} * 365 \text{days})$$

$$\text{Loss per connection} = (960,175 * 1000 \frac{1}{\text{m}^3}) / (17,729 * 365 \text{day}) = 148.38 \text{ L/c/day.}$$

This indicates as when number of connection increases water loss also increase in the distribution system.

4.2.2 Water loss as per pipe length

Among the appropriate indicator of water loss in water distribution system water loss expressed as per kilometer length of main pipes is the one which is also used as indicator to compare water loss. With different age category total length of pipes greater or equal to 50mm diameter have been used to evaluate total water loss of the entire town is 53.41km .

Table 4.6: Summery pipe length with age category

No	Age category (year)	Pipe length (km)	% of cover (km)	Remark
1	≤ 10	17.37	55.26	Distributer
2	10-20	29.52	32.52	Distributer
3	20-30	6.53	12.22	main line and Distributer
	Total	53.409	100	

(Source: Debre Brehan water supply office)

Water loss per kilometer length of main pipes was derived to as, $(960,175 * 1000 \frac{1}{\text{m}^3}) \div (53.41 \text{km} * 365 \text{days}) = 49,253.26 \text{ litter/km/day.}$

4.2.3 Components of water loss

Non-revenue or total loss is the sum of real loss (UARL) and apparent loss. But due to the limitation of required data to directly compute total real loss in the Debre brehan water supply distribution system IWA expression was used which is a good indicator for water loss in water supply distribution network. **Unavoidable Average Real Losses (UARL)**: It is recommended that the calculation of the UARL in liters/service connection/day is based on the following form of equation.

$$\text{UARL (liters/day)} = 18 \times L_m + 0.8 \times N_C + 25 \times L_P \times P$$

Where L_m = Mains length (km) N_C = number of service connection L_P = total

Length of private pie, property boundary to customer meter (km) P = average pressure (m).

$$\text{UARL (liters/day)} = ((18 \times 53.41) + (0.8 \times 14,281) + (25 \times 0)) \times 38.49$$

$$= 476,725.49 \text{ (liters/day) or}$$

$$= 174,004.80 \text{ m}^3/\text{year} \text{ which covers 6.78\% from the total non-revenue water}$$

According to table 4.4 the current total water loss in the water supply distribution system is 960,175 m^3/year therefore;

$$\text{Apparent Loss} = \text{NRW} - \text{UARL}$$

$$= 960,175 \text{ m}^3/\text{year} - 174,004.80 \text{ m}^3/\text{year}$$

$$= 786,170.20 \text{ m}^3/\text{year} \text{ which covers 30.62\% from the total non-revenue water}$$

4.3 Major factors contributes to water loss in Debre Brehan town

In Debre Brehan town water supply distribution system there are a number of causes for high level of water loss these cause are listed and expressed as follows.

4.3.1 Pipe burst and leakage

Pipe burst is one of the key issues that affect urban water distribution systems, and can lead to water supply interruption due to high amount of water loss, property damage, and water quality problems. If the time of the pipe burst incidents can be anticipated beforehand, a pipe network maintenance plan can be formulated in advance to avoid the accidents. Pipe bursts can be broadly attributed to hydraulic and non-hydraulic factors. The hydraulic factors are the hydraulic transient shock and cavitation caused by the operation of pumps and valves. The non-hydraulic factors include pipe stress, pipe corrosion, foundation failure and the quality of pipe material. Water leakage are caused by small or large breaks in the pipes, which occur at main pipe level and along the pipe connection properties. The technical literature classifies leakages in back ground and bursts (unreported or reported) depending the level of out flow. Therefore, background leakage are diffuse and small

outflows along run over time and causes significant water loss. In Debre Brehan town water supply distribution network in addition to both hydraulic and non-hydraulic factors due to cold climate characteristics of the town the water forms hard snow in the pipe as the result of this during high pressure situation frequently pipe burst was happened. Therefore this frequent pipe burst have significant contribution for physical water loss in the town water supply distribution network. In this town leakage due to pipe burst from both transmission main line which having the diameter of 110, 150, 200, 250, 300, 350 & 400 and distributed main line which having the diameter of 50, 75, 80, 90, 100, 110, 150, 200 & 300 is determined as $172,493.05\text{m}^3/\text{year}$ by using Greelay's formula *equation (3.5)* in the methodology part and while based on DBWSS operation and maintenance report data. According to this report the average duration of repairing time for transmission and distribution main line is two & one hours respectively with the frequency of one times on each main lines thus the total is seven times per year & two times on each distribution line with total of eighteen times per year the detail calculation is elaborated at *appendix-VIII*. Thereby, water leaks through cracks and connections can be estimated by subtracting the above gained water leak through diameter of pipe from the total real loss which is $174,004.80\text{ m}^3/\text{year} - 172,493.05\text{m}^3/\text{year} = 1,511.75\text{m}^3/\text{year}$

4.3.2 Meter inaccuracy

The water meter is an essential tool for both the utility and the customers to measure and monitor consumption. When metering is inefficient and coupled with low tariffs, the financial sustainability of utilities is at stake. Apparent water losses caused by metering inefficiencies can be reduced by assessing meters' performance and identifying the main causes of inefficiency. According to the town water service office; among the total of 14,281(class B, dry dial, multi-jet) type of customer water meter; 9525 DN 25mm, 2452DN 20mm, 1412DN25mm, 862DN 32mm and 12DN90mm, and most of these meters are manufactured in china whereas; the remaining others made in Italy, French, Israeli, Germen and India. Since Derbre Brehan town is far from the regional state town Bahir Dar and due to the absence of water meter laboratory in the town water supply office water meter test was computed in Addis Ababa water meter laboratory office Lamberet branch. According to this water meter laboratory branch office report; 200 l/c/d water meter testing flow rate was taken for all type and brand of water meter as testing bench. As a result of this the water loss due to this meter inaccuracy is estimated as $82,350.29\text{m}^3/\text{year}$ by comparison this testing bench figure and the average

water meter reading value of customer water meter obtaining from current year authorized revenue water. The calculation is explained in the table below.

Table 4.7: Annual water loss results from customer water meter inaccuracy.

Description	No of meter	Total authorized revenue water, 2016	Average meter reading (per connection)	Meter testing flow rate	Difference	Total water Loss (l/c/d)
	A	B	$C = B/A$	D	$E = D - C$	$F = E * A$
All customer Water meter	14,281	2630616.44 liter/day	184.20 l/c/d	200 l/c/d	15.8 l/c/d	225639.8 or 82,350.29 m ³ /year

4.3.3 Poor maintenance practice

In Debre Brehan town water supply distribution system observed that there were maintenances practice for the distribution system at the entire town especially frequently pipe burst and highly injured supply system area like; Seponji Meda, Ansas Mariam and Tebase. But due to the presence of limited professional man power, lack of enough budget to buy qualitative spare material and to pay for man power those implemented during maintenance and support the skilled man, lack of fast information during injured in the distribution system and lack of maintenance instrument like pipe wrench. Therefore, as a result of this there were valuable impact to contribute physical water loss in the town water supply distribution system.

4.3.4 Legal unbilled connection

This includes the amount of water consumed by the town water supply office workers. In Debre Brehan water supply office currently there are 84 workers. These workers uses water free for different purpose in the three administrative office and at their home for domestic purpose until it reach 82 birr for each worker in each month. According to the town water supply office, the average water tariff in the town 5.28 birr/m³ therefore the total volume non-revenue of water lost due to this metered unbilled consumption was estimated as; $((84+3)82 \times 12) / 5.28 = 16,214 \text{ m}^3/\text{year}$.

4.3.5 Illegal connection

In Debre Brehan water supply distribution system there are several illegal water utility users these unauthorized consumers received water from the distribution system by informal connection way

and they do not gave payment tariff to the town water service office especially this situation has been happened in the town area having relatively low topographical location which is water easily reached and highly expansion areas like Sponji Meda, Aquasafe and around Anisas Mariam. According to water service office report data and result of water balance determination, water lost due to illegal connection in the town is likely estimated as 55,984.75m³/year and also since the illegal connection was usually laid just near to the surface and the pipe material which used for this purpose were easily gained and less cost as result of this the pipe were highly exposed to damage and water loss was taking part.

4.4 Proposed water loss management practice in the distribution system

Water Loss Management encompasses strategies and tools to assist water utilities in their important goal of reducing non-revenue water. This can be achieved by decreasing real losses due to leakage in the water network or reducing apparent loss due to inaccuracy in revenue metering. Water utilities count water loss management techniques as one of the most cost-effective interventions in saving water. For this study some of practice to control water loss in water supply distribution network were identified and presented below.

4.4.1 Leakage monitoring

Leakage monitoring can be classified into two groups including passive leakage control and active leakage control.

Passive leakage control (PLC): is reacting to reported bursts or a drop in pressure, usually reported by customers or noted by the company's own staff while carrying out duties other than leak detection. This method can be justified in areas with plentiful or low cost supplies. Often practiced in less developed supply system where the occurrence of underground leakage is less understood, it is the first step to improvement.

Active leakage control (ALC): is when company staff is deployed to find leaks which have not been reported by customers or other means. The main Active leakage control methods are regular survey and leakage monitoring. Regular survey is a method of starting at one end of the distribution networks and proceeding to the other using one of the following techniques: - listening for leaks on pipe-work and fittings, Reading metered flows into temporarily-zoned areas to identify high-volume night flows and Using clusters of noise loggers (leak localizing) Leakage monitoring is flow monitoring into zones to measure leakage and to prioritize leak detection activities. This has now become one of the most cost effective activities for leakage management programs.

4.4.2 Pressure management

The pressure management is the preventive method ‘par excellence’ because it is the only one that reduces the flow of all types of leakage (background, unreported and reported) without replacing existing infrastructure (Thornton & Lambert, 2007). The most efficient and effective way of managing pressure is to control water loss and reducing leakage in the distribution system. Reduction of pressure will reduce background leakage, the break rate on main and service connections and of course the flow rate from any leak. The savings are therefore significant, which became even more obvious as the understanding of the pressure leakage relationship was further improved. Apart from fixed outlet pressure control which provides the biggest water loss savings over no pressure control, advance pressure management (further pressure reduction during periods of low demand and excessive pressure) is used as a means for further water loss savings in areas where it is found to be feasible and economically justifiable. In Debre Brehan town water supply distribution system with some place which having relatively low geographical position from the supply tank like Sponji Meda, Ansa Mariam and some parts of Tebasse were exposed to high pressure during low consumption time. Therefore at those areas still there are functionless pressure reducing valve so it should be replaced by new and efficient valves to control the existing high pressure at these areas.

4.4.3 Improve efficiency of water office organization

A strong management and organizational setup is the main reason for a leakage management practice in the water supply services and to the satisfaction of the customers. The most appropriate leakage control strategy will mainly be dictated by the characteristics of the network and local conditions, which may include financial constraints on equipment and other resources. Staffing resources are relevant, as a labor intensive methodology may be suitable if manpower is plentiful and cheap. If the geology of the area allows a high proportion of leaks to appear at the surface, a strategy of regular survey followed by rapid repair may be adequate. According to Debre Brehan water supply and sewerage office, there are 84 workers under the three administrative office. The head of these three administrative office and belong of each office; technical staff and financial staff are accountable to the general manager. The scheme have only twenty operational and maintenance worker. Among these three are contract and other seventeen are permanent employed. But these worker are not able to address all area to solve the current extremely water supply distribution network damage problem including frequent pipe burst in the town. Moreover, in the town water supply and sewerage office there is no enough committed technical as well as administrative organization.

4.4.4 Economic analysis of water tariff

One of the water loss management strategies in the water utilities is the water tariff carried out in the system. According to Debre Brehan water utility office, there are different water tariff in the town based on customer type and volume of water consumed. The town water tariff is summarized as in the table below.

Table 4.8: Debre Brehan water supply utility office water tariff

No	Consumption	For HC and	For Gov't and Non	For Commercial and
		PF	Gov't organization	Industry
		Tariff p/m ³	Tariff p/m ³	Tariff p/m ³
1	0-5	3.75	4.00	5.00
2	5-10	4.00	4.50	5.50
3	10-15	4.50	5.00	6.00
4	15-25	5.00	5.50	6.50
5	25-40	5.50	6.00	7.00
6	> 40	6.00	6.50	7.50
7	PF	2.50	-	-

Source: Debre Brehan town water supply service office, water Tariff document.

From the above table 4.7; taken the average unit price of 5.28 birr/m³ and financially, the water utility were lost $960,175 \times 5.28 = 5,069,724$ birr/year from authorized total water loss. Therefore, from this figure it was observed that; the general water loss management trends of Debre Brehan town water service system were in poor status, and the utility was given less attention for water loss.

4.5 Distribution system modeling analysis

4.5.1 Population and average water demand forecasting

To project the current population (2016) of the Debre Berhan town based on last population census report population and housing census report of 160,408 (2012), which was prepared by Ethiopian Central Statistical Agency. According to CSA, the current (2016) regional level annual growth rate for urban population was assigned as 4.4%. However the exponential population forecasting method has been used and the average water demand of the town has been estimated by multiplying the estimated population by corresponding estimated per capita demand of the town the current estimated per capita demand of Debre Brehan town is 23.24 l/c/d. The estimated population and corresponding average per capita demand of the town is presented in the table below.

Table 4.9: Population Growth rates

Year		Growth rate (%)
2006	2011	4.9
2012	2016	4.4
2017	2021	4.5
2022	2026	4.3
2027	2031	4.1
2032	2036	3.93

Source: CSA (2012) National census figures

Table 4.10: Debre Brehan town projected population figure (2016-2036)

Description	Unit	2012	2016	2021	2026	2031	2036
Urban Growth Rate	%		4.4	4.5	4.3	4.1	3.93
Urban Population	No	160,408	191,277	239,541	296,998	364,572	443,733
Per capita consumption	(l/c/d)	23.24	23.24	23.24	23.24	23.24	23.24
Average water demand	l/s	43.15	51.45	64.43	79.89	98.06	119.36

Based on the result of the table above the projected population of Debre Brehan town was 191,277 (2016), 443,733 (2036) and the corresponding average water demand was 51.45 l/s and 119.36 l/s.

4.5.2 Water distribution system analysis

Analysis of water distribution network consists of many system elements such as Reservoir, Tank, Pipes, Pumps, Valves and Junctions. The layout of Dere Brehan town water distribution network is drawn from the looped system type of layout Auto CAD drawing and the system contain the above mentioned elements. The town water CAD modeling layout is illustrated in the figure 4.2 below.

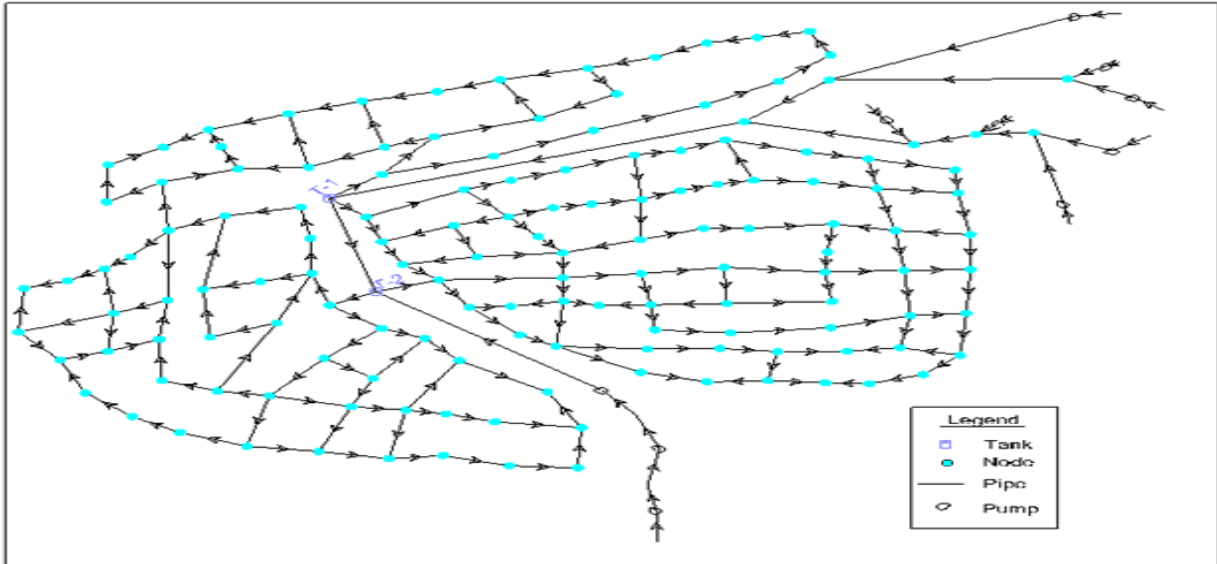


Figure 4.2: Debre Brehan town water supply distribution network

Table 4.11: Description of modeling system components

Component system	Number
Pump	10
Tank	2
Pipe	212
Junction	143
PRV	5

According Debre Brehan town water supply office information there two type pipe material in distribution layout most of pipe material cover PVC which is 61.83% and the remaining 38.17% is DCI. For this study to model synchronize simplicity pipe diameter taken was from 50mm to the maximum diameter 400mm and 150mm diameter covers much amount which is 29.51% when compared to the other pipe diameter in the town water supply distribution system. The detail is tabulated as on the table 4.12 below and on the *Appendix-II*.

Table 4.12: Summary of Description of pipe length in the WSDS.

Diameter (mm)	Length (PVC) (m)	Length (DCI) (m)	Length (All Materials) (m)	Volume (m ³)	% of Cover
50	2,118	405	2,523	4.95	4.72
75	3,620	0	3,620	15.99	6.78
80	8,905	0	8,905	44.76	16.67
90	2,321	0	2,321	14.77	4.35
100	4,065	347	4,412	34.65	8.26
110	220	0	220	2.09	0.41
150	11,772	3,989	15,761	278.52	29.51
200	0	9,122	9,122	286.58	17.08
250	0	2,246	2,246	110.25	4.21
300	0	2,570	2,570	181.66	4.81
350	0	1,430	1,430	137.58	2.68
400	0	279	279	35.07	0.52
Total	33,021	20,388	53,409	1,146.87	100.00

4.5.3 Reservoir capacity description

A reservoir location should maintain the desired pressure range in the supply network. Possible future extension of the storage capacity should be taken into consideration when selecting a site. The service reservoir (storage tank) is provided to balance (constant) supply rate from the water source or treatment plant with the fluctuating water demand in distribution area. Dynamic (EPS) simulation result was used to show the fluctuating storage volume with time increments during high and low consumption. According to Design Manual of MoWR (2006), peak hour factor (PHF) population number greater than 50,001 is 1.8 as a result to get *Peak Hour Demand (PHD)* of the town, *Average day demand (ADD)* should be multiplied by *peak hour factor (PHF)* which is;

$$\begin{aligned}
 \text{Peak Hour Demand (PHD)} &= \text{Average Day Demand (ADD)} * \text{Peak Hour Factor (PHF)} \\
 &= 51.45 \text{ l/s} * 1.8 \\
 &= 92.61 \text{ l/s}
 \end{aligned}$$

By comparing this with peak hour demand with 24 extended period simulation result of the storage tanks which is as can be seen in figure below fluctuation of out flow from both tank-1 and tank-2 is at peak hour demand time at 8:00 hour is 63 l/s and 69 l/s respectively and the summation of out flow from these two tanks is 132 l/s among this out flow 37.4% is loss therefore; the net out flow is 49.37 l/s which is below peak hour demand (PHD) of the town 92.61 l/s therefore; the capacity of tanks in the distribution system is low.

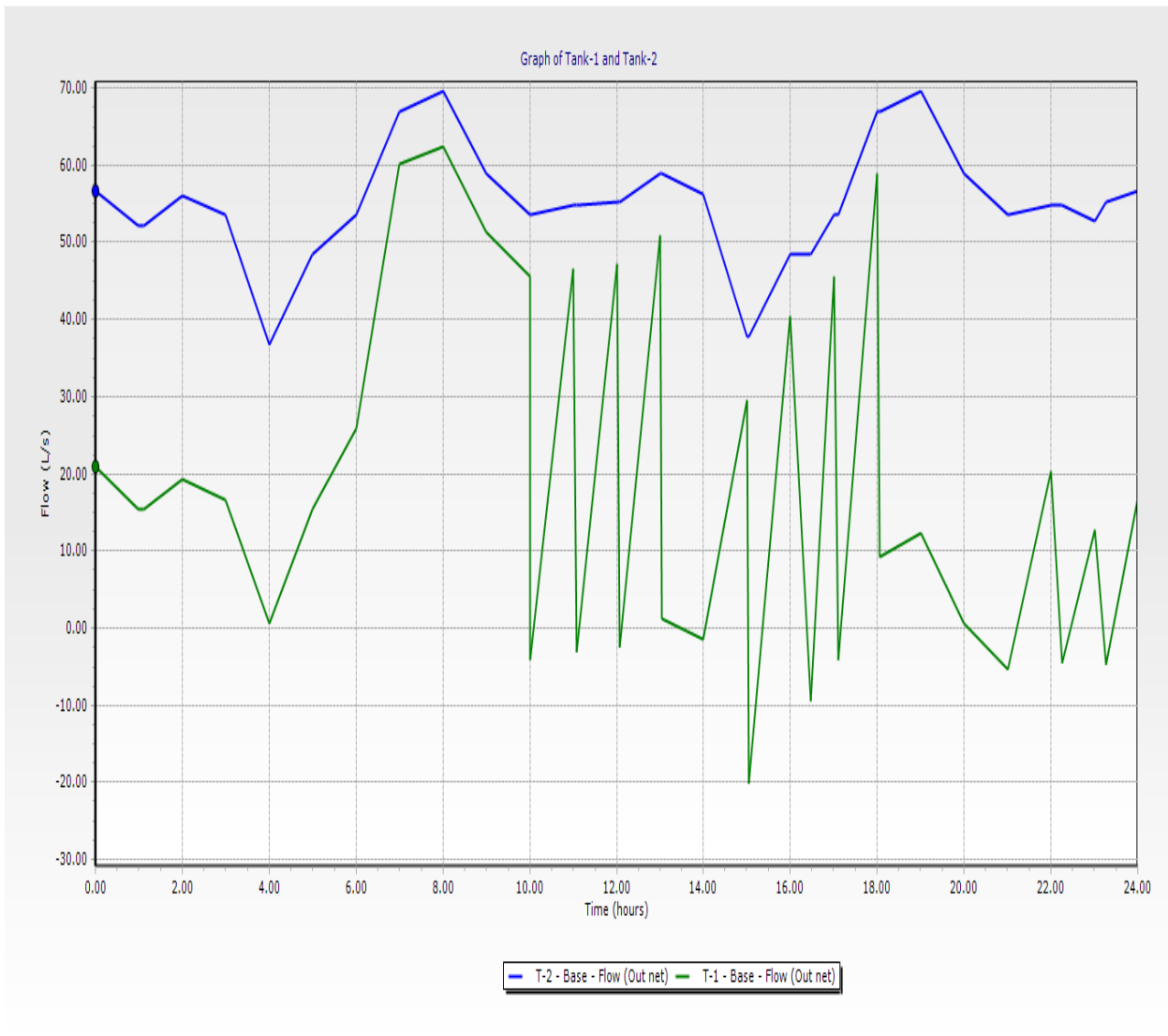


Figure 4.3: fluctuation of out flow from tanks.

4.5.4 Pump

Where the water source is located much higher than the user's distribution network system may flow entirely by gravity. However, in most case a pump is needed to provide the necessary pressure and flow. In Debre Brehan town there are ten bore holes as source of potable water for the entire town

and each bore holes has design point (one point) pump type these pumps have their own design head and flow based on this data using water CAD the result is simulated as shown below on the table.

Table 4.13: Pump simulation result from design input value

No	Pump Name	Elevation (m)	Design in put Value			Simulation Result			
			Head (m)	Flow (l/s)	Efficiency (%)	Head (m)	Flow (L/s)	Efficiency (%)	H.G (Suction)(m)
1	pump-1	2,810.82	83	7	85	48.75	10.47	38	2,810.14
2	pump-2	2,789.00	66	8	85	48.05	7.16	42	2,809.92
3	pump-3	2,806.53	74	5	85	58.17	14.04	44	2,805.04
4	pump-4	2,813.37	86	10	85	49.71	15.05	37	2,812.15
5	pump-5	2,806.15	59	12	85	54.91	13.19	58	2,804.85
6	pump-6	2,804.28	60	5	85	52.7	5.84	56	2,804.15
7	pump-7	2,804.32	60	5	85	50.55	6.07	54	2,804.10
8	pump-8	2,766.96	56	15	85	5.45	28.89	7	2,761.85
9	pump-9	2,761.29	39	15	85	6.74	27.99	10	2,754.99
10	pump-10	2,767.68	70	15	85	71.32	14.57	66	2,759.56

As can be seen from table 4.13, even though, most pumps perform in a good condition have an efficiency range between 60 and 80% (ISO 9906:2012), except pupm-10 all other pumps in Debre Brehan town have below the minimum efficiency range particularly pupump-8 and pump-9 have very low head and efficiency.

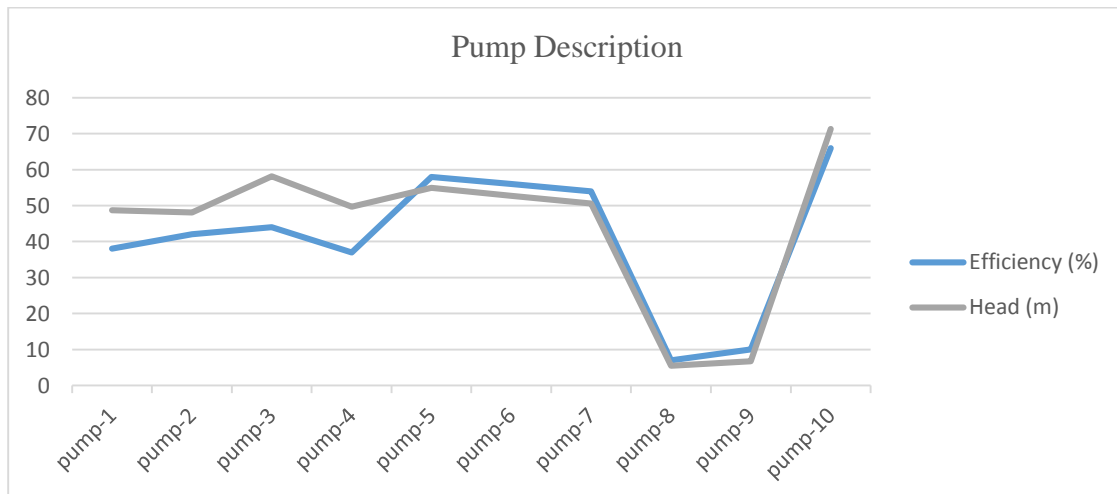


Figure 4.4: Pump definition result

4.5.5 Pressure

The pressure needed to supply water through the water supply pipe network and it also cause for water loss in several ways through increasing leakage and pipe burst frequency especially this phenomena is happen during low(night) water demand time. The detail pressure distribution in Debre Brehan town water supply system is can be seen on the *Appendix-IV* and *VI* during low and high demand time respectively. 32% of the total nodes have pressure value which is greater the than the recommended value 60(mH₂O) particularly nodes 34,11,16,49 and 47 have pressure 109.07, 104.74, 105.63, 96.66 and 92.65 (mH₂O) respectively during low water consumption time and as the result of this pressure and very hard ice formation in pipe there is high pipe burst frequency in the town. Whereas, during high water consumption among the total node about 18% nodes are below minimum pressure range value 15(mH₂O) and this also indicates that there is no sufficient water at these nodes. The variation of pressure distribution in the town water supply distribution network during low and high demand time is shown in the following figures below.

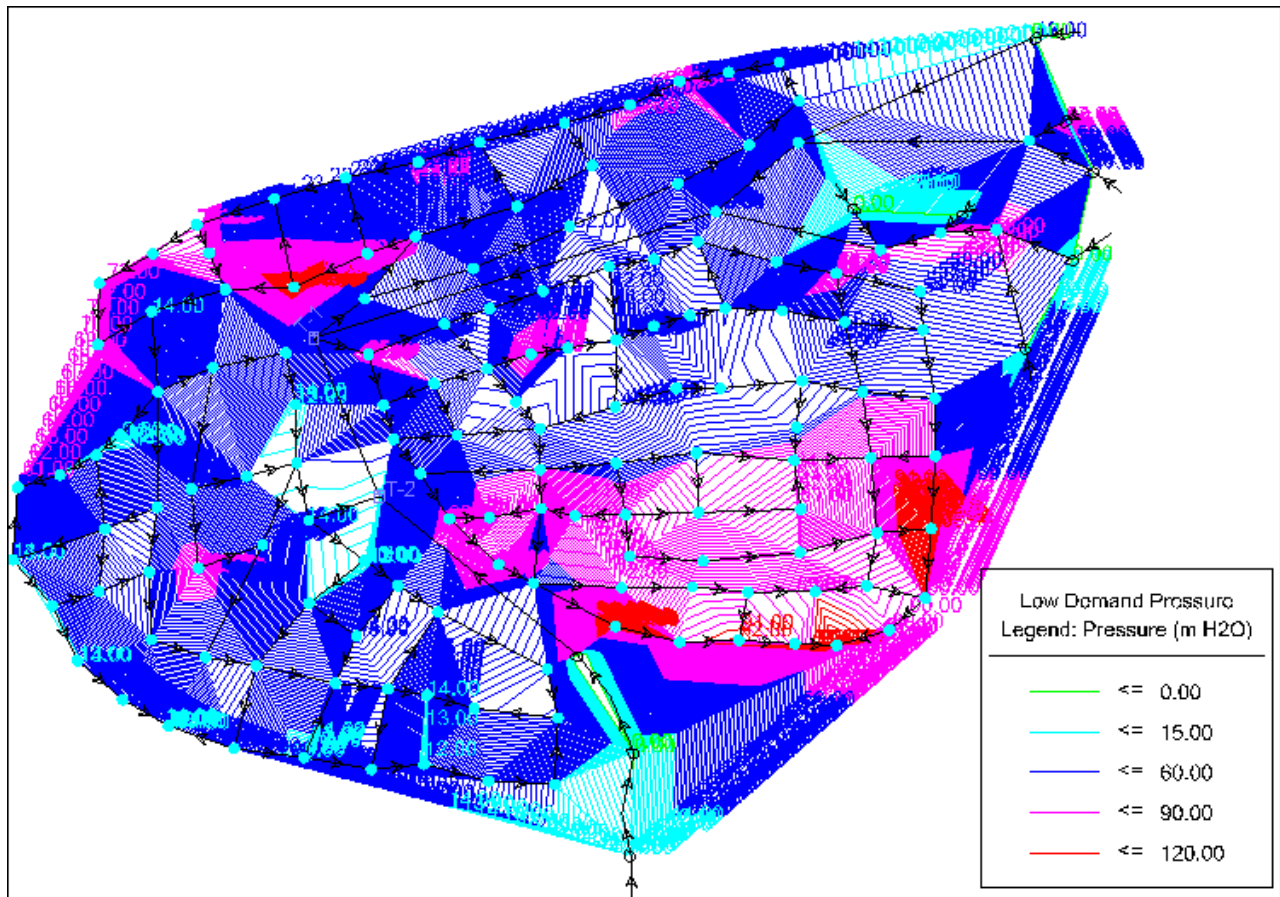


Figure 4.5: Debre Brehan town pressure distribution at low demand time.

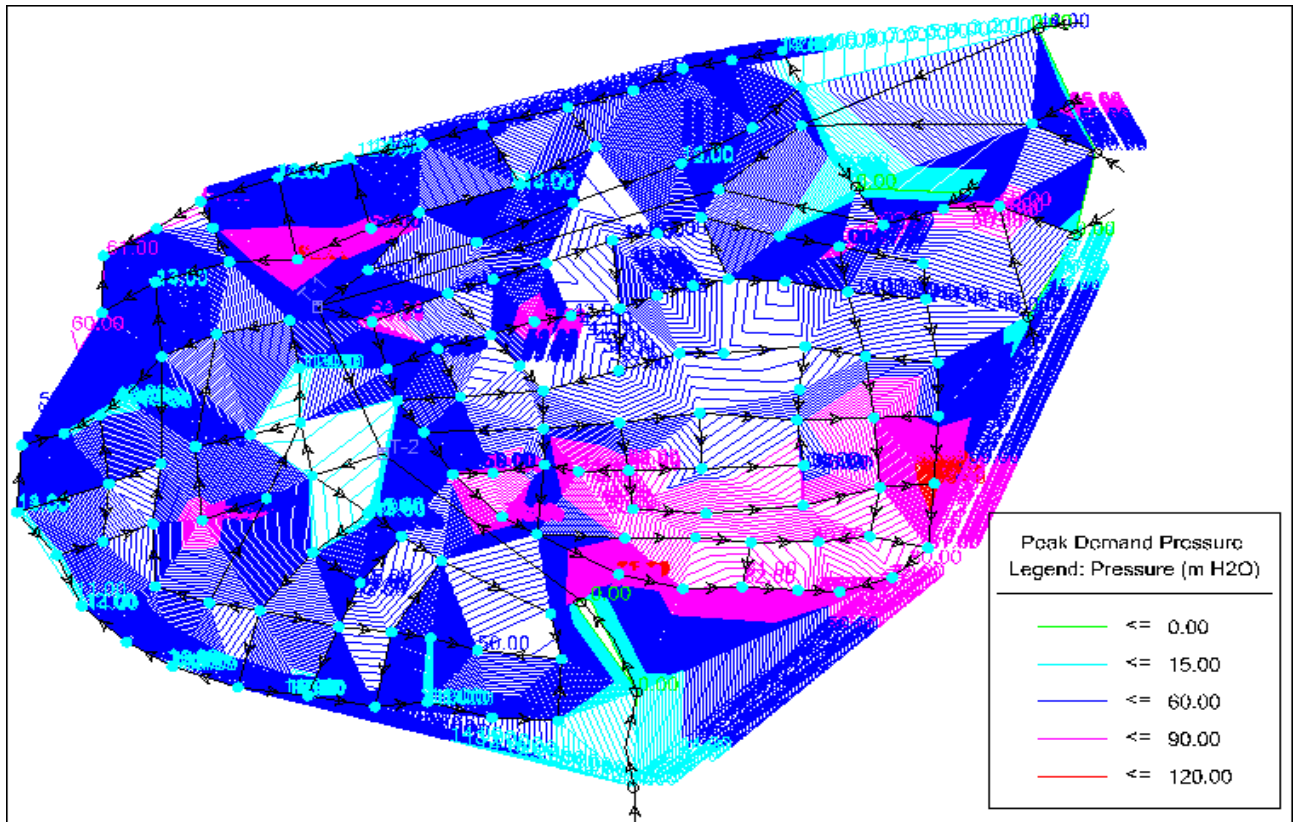


Figure 4.6: Debre Brehan town pressure distribution during peak demand time.

4.5.6 Hydraulic modeling calibration and validation

In hydraulic models the required data have been collected and entered into a simulation software package, the modeler cannot assume that the model is an accurate mathematical representation of the system. The hydraulic simulation software simply solves the equations of continuity and energy using the supplied data. Thus in order to calibrate and validate the models and for comparison purposes, some quantitative information is required to measure model performance. In this study, the pressure data measured at the near to node home faucet of the system was used to assess the model performance. The performance assessment was based on the pressure measured and simulated data by model, the agreement of the overall the time series of pressure the value of the statistical performance indices (Legates, 1999) such as the degree of accuracy (error of difference) and the goodness of fit tests (R^2) are two techniques to be considered for calibration model test as mentioned below with both peak demand (day flow) and low demand (night flow) time.

Table 4.14: Comparison between simulated and observed pressure value during peak demand time

Sample Nodes	Location			Simulated Pressure (m)	Measured Pressure (m)	Error (m)	Time Measure
	X (m)	Y (m)	Elevation (m)				
J-127A	553,210.12	1,066,728.41	2,781.04	47.50	48.02	0.10	7 AM To 6 PM
J-17	559,451.90	1,071,206.90	2,802.64	37.09	40.13	-0.27	
J-216	557,475.22	1,065,108.81	2,799.87	29.79	28.85	1.06	
J-217	557,623.00	1,068,603.46	2,788.64	41.11	39.93	1.28	
J-30A	560,427.84	1,068,483.91	2,782.22	66.63	58.31	8.36	
J-54	562,063.14	1,070,126.20	2,826.41	11.53	13.75	-0.20	
J-59	563,569.06	1,068,244.09	2,806.69	38.77	35.12	4.71	
J-12	565,508.32	1,072,112.42	2,790.66	51.51	53.34	0.21	
J-20	566,346.23	1,071,197.52	2,817.15	12.81	11.57	1.25	
J-23	557,173.87	1,241,068.98	2,818.40	22.16	25.19	-1.39	
Average						-0.47	

Table 4.15: Comparison between simulated and observed pressure value during low demand time

Sample Nodes	Location			Simulated Pressure (m)	Measured Pressure (m)	Error (m)	Time Measure
	X (m)	Y (m)	Elevation (m)				
J-127A	553,210.12	1,066,728.41	2,781.04	49.03	48.64	-0.39	7 PM To 6 AM
J-17	559,451.90	1,071,206.90	2,802.64	46.02	50.48	4.46	
J-216	557,475.22	1,065,108.81	2,799.87	30.13	29.31	-0.82	
J-217	557,623.00	1,068,603.46	2,788.64	41.36	41.23	-0.13	
J-30A	560,427.84	1,068,483.91	2,782.22	66.77	63.37	-3.40	
J-54	562,063.14	1,070,126.20	2,826.41	20.39	22.76	2.37	
J-59	563,569.06	1,068,244.09	2,806.69	42.18	44.10	1.92	
J-12	565,508.32	1,072,112.42	2,790.66	58.09	61.53	3.44	
J-20	566,346.23	1,071,197.52	2,817.15	12.85	13.54	0.69	
J-23	557,173.87	1,241,068.98	2,818.40	29.11	33.60	4.49	
Average						1.26	

As shown in Table 4.14 and 4.15; the average pressure value of during both peak and low demand time is (0.40m) which is the difference between simulated and measured pressure value at each sample node in the distribution system. According to Pressure Criteria (Bentley Water CAD/GEMs, 2008), the model is acceptable calibrated which is satisfied the setting pressure calibration and validation criteria under average level (average ± 0.5 to the maximum ± 5 m). Whereas, the graphical representations of pressure value of both peak and low demand time is shown in the figures below.

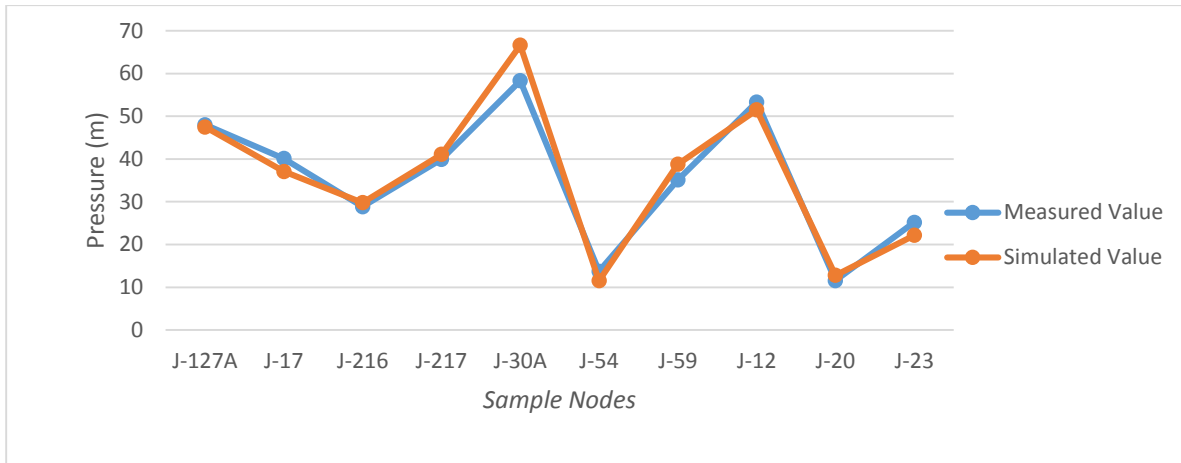


Figure 4.7: Graphical representation of simulated and measured pressure Value during peak demand time



Figure 4.8: Graphical representation of simulated and measured pressure Value during low demand time

- **Validation**

Coefficient of determination (R^2) describes the degree of co linearity between simulated and measured data. The coefficient of determination (R^2), is ranges between 0 and 1, describes the proportion of the variance in the measured data, which is explained by the model, with higher values indicating less error variance. Typically, $R^2 > 0.5$ is considered acceptable (Singh, 2004, Santhi, 2001). The Coefficient of determination (R^2) equation is shown as below.

$$R^2 = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}}$$

Where: R^2 = Coefficient of determination, X and Y are the measured and simulated pressure values, and \bar{X} and \bar{Y} are mean value of observed and computed pressure respectively.

As shown in figure 4.9 and 4.10; it explain the results of correlation value (R^2) for both peak and low demand time was represent as 96.46% and 97.71%, respectively. Thereby, the calibrated pressure value was validated within the recommended standard.

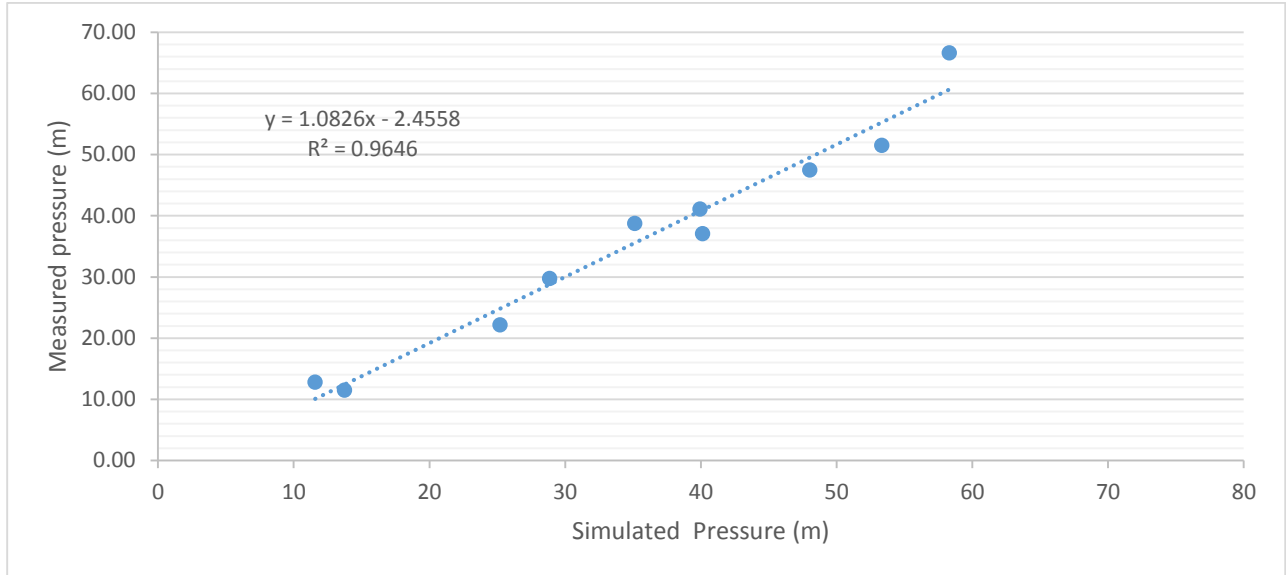


Figure 4.9: correlation between simulated and measured pressure Value during peak demand time

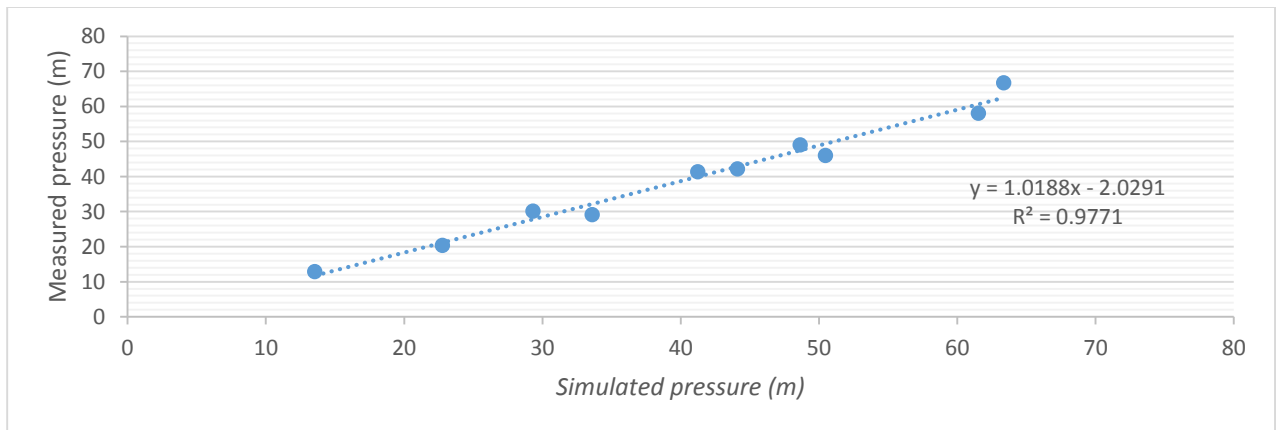


Figure 4.10: correlation between simulated and measured pressure Value during low demand time

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The average water supply coverage and distribution were evaluated based on the daily per capita consumption and level of connection using the population and water consumption data of each kebele in Debre Brehan town for the year 2016. The average water supply coverage of the town is 23.24 l/c/d. This average per capita consumption was less than as compared with some water supply standards, according to (Wallingford HR, 2003), the minimum quantity of domestic water required in developing countries in urban areas 25 l/c/d. Although the distribution of water supply coverage within the town (among each Kebele) has variation, the amount average per capita water consumption with in each Kebele is still below the standard. The existing pipes of the distribution pipe system do not cover all areas of the town. Uneven distribution of water and the spatial distribution of the pipe network system fail to satisfy the demand of the public. In addition, some part of the town that are located at higher elevation and those areas located closer to the reservoir site do not get the minimum required water pressure.

The town water supply coverage declines in the year between (2011-2016) due to increasing of population who shares water supply production. Whereas, the current net production of water from ten bore hole is 36.28 l/s which is much less than the demand of the town by mode of service 86.39 l/s due to the presence of high water loss in the distribution system.

In spite of the low water coverage and distribution of the town, there is high level of total water loss in the distribution system, the total water loss was computed by subtracting the water consumption (1,607,381m³) data from the water production (2,567,556m³) data is (960,175m³) this means 37.40% of the production water is accounted for loss in 2016 at the town level,

Two ways were identified that examinations of magnitude and distribution water loss in the water supply system these are loss per length of pipe and per connection. Physical losses contributes considerable volume of water losses. While, apparent losses are more significant and the major sources of water losses in the town water supply distribution system. Generally, leakage and pipe burst are the main source of real water loss whereas, meter inaccuracy, poor maintenance practice, legal unbilled and illegal connection are accountable to apparent loss in Debre Brehan town.

Whereas, Pressure based hydraulic performance evaluation indicated that acceptable minimum and maximum pressure have not been meet. During peak hour demand flow, parts of the distribution system receive water with low pressure and under some circumstances risk of obtaining no water is

observed because of the pressure in the distribution system is beyond permissible minimum requirement. In other way, some parts of the distribution system is prone to undesirable pressure which exceeds maximum allowable pressure. As a result, the distribution system is exposed to risks of high leakage and repeated pipe breakage during low demand flows. And also in contrast the size and capacities of existing infrastructural components such as clear water reservoirs, pumping stations and distribution pipes were found small in capacities, and leads to low water supply coverage and distribution in the town.

5.2 Recommendations

To improve the water supply services of the town in terms of coverage, distribution performance, water demand and reducing water loss the following actions should be undertaken.

- ❖ Since the current water production system does not satisfy water demand of the town necessary action should be taken to improve the performance of water supply system including increasing additional source of water, installing stand by generator at all existing pump station.
- ❖ In order to improve the water supply distribution system and regulate the variation of pressure additional valves should be installed and repair the existing functionless valves. Since supply reservoirs are found relatively at high elevation therefore, as result of absent appropriate valves installation water is flow with high velocity to lower elevation area and this is causes for unfair distribution of water and pipe burst in the supply system.
- ❖ At the time of water loss analysis, large amount of water was lost by leakage & pipe burst and customer meter inaccuracy and frequent damage. Therefore, it is recommended that; it needs good pressure management strategies, old and injured; pipe, fittings and water meter should be replaced by new and qualified materials which able to resist the cooled weather condition of the town and other cause of material damage. Whereas, other infrastructural expansion like road should be integrated with water works and they should be reduce their contribution of water infrastructural damage in the town.
- ❖ Poor maintenance practice, legal unbilled connection and illegal connection were have their own great effect for the water loss in the distribution network. So, appropriate and continues training should be given to maintenance worker and the community should give information soon during the time of damage is happen in the distribution system while those communities should be responsible to use water properly and legal way. In order to do this community awareness creation about proper use of water and keeping the supply system is expected from the town water service office worker and other stakeholders.
- ❖ Effective data gathering, organization and handling culture is also the other basic problem in the town water service office. As result of this, it is not able to manage properly the water service and keeping wellness of the distribution network. Therefore, the water service office should be collect, organized and handle the data with modern computer supported form.

- ❖ During the supply distribution network analysis; it is observed that, the currently water pipe network installation method carried out traditionally and almost all are looped type network without installation of necessary valves and accessories in order minimize the risk of pressure variation risk, water hammer and back water flow. But, AAWSA has to be prepared the working guideline manuals for the purpose of new pipe installation, age pipe replacement and upgrading existing pipe size, extending the pipe to new expansion area and installation of new pipe size based on demand calculation and topographic conditions of the town.

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APPENDIX**Appendix-I****In Put Base Demand to Bentley Water GEMS V8i software**

No	Label	House	Population	Base Demand	Coordinate Point		
					X	Y	Elevation (m)
1	J-115	412	1648	0.44	559,136.91	1,066,419.80	2,793.86
2	J-201	350	1400	0.38	560,494.34	1,067,338.58	2,791.96
3	J-102B	250	1000	0.27	558,849.75	1,066,226.24	2,794.69
4	J-104	256	1024	0.28	558,144.84	1,065,670.60	2,796.01
5	J-105	167	668	0.18	557,851.67	1,066,452.71	2,816.50
6	J-105A	350	1400	0.38	559,248.03	1,067,132.91	2,787.40
7	J-105B	487	1948	0.52	558,373.07	1,066,738.60	2,784.65
8	J-105C	87	348	0.09	588,373.09	1,067,106.77	2,821.24
9	J-107	189	756	0.20	557,236.77	1,065,774.77	2,792.37
10	J-109	176	704	0.19	557,216.97	1,066,588.39	2,815.10
11	J-111	403	1612	0.43	556,184.50	1,066,496.75	2,790.32
12	J-112	250	1000	0.27	557,027.77	1,067,300.49	2,818.49
13	J-113	276	1104	0.30	555,982.46	1,067,500.97	2,799.50
14	J-114	543	2172	0.58	555,532.15	1,067,245.10	2,778.24
15	J-114A	543	2172	0.58	556,370.57	1,063,058.29	2,769.71
16	J-120	578	2312	0.62	555,904.39	1,063,300.19	2,818.46
17	J-121	456	1824	0.49	555,246.91	1,063,548.63	2,791.08
18	J-122	367	1468	0.40	555,080.62	1,064,221.07	2,817.22
19	J-123	265	1060	0.29	556,101.56	1,064,054.02	2,816.36
20	J-124	452	1808	0.49	555,197.69	1,066,747.77	2,783.05
21	J-127	530	2120	0.57	555,069.87	1,066,196.96	2,788.09
22	J-127A	510	2040	0.55	553,210.12	1,066,728.41	2,781.04
23	J-133	653	2612	0.70	562,708.83	1,067,103.00	2,769.67
24	J-159A	518	2072	0.56	556,604.57	1,068,127.13	2,801.42
25	J-16	523	2092	0.56	561,662.54	1,067,547.70	2,743.00
26	J-162	590	2360	0.63	559,271.99	1,066,069.37	2,790.44

27	J-163	578	2312	0.62	559,530.17	1,065,779.13	2,788.30
28	J-167A	587	2348	0.63	559,830.14	1,065,489.21	2,815.95
29	J-167C	487	1948	0.52	559,847.71	1,066,271.31	2,778.74
30	J-167E	487	1948	0.52	560,805.78	1,065,277.24	2,778.39
31	J-167F	467	1868	0.50	560,332.93	1,066,504.12	2,780.15
32	J-168	578	2312	0.62	556,502.63	1,068,647.67	2,790.75
33	J-17	456	1824	0.49	559,451.47	1,071,206.90	2,802.64
34	J-170	456	1824	0.49	553,930.30	1,067,129.49	2,793.19
35	J-174	468	1872	0.50	554,423.34	1,068,207.48	2,811.78
36	J-18	352	1408	0.38	556,897.17	1,068,953.54	2,800.91
37	J-208	598	2392	0.64	552,853.51	1,067,895.13	2,814.24
38	J-208A	487	1948	0.52	553,252.92	1,068,667.68	2,821.59
39	J-21	97	388	0.10	554,462.11	1,069,188.95	2,787.95
40	J-210	753	3012	0.81	555,934.30	1,065,297.51	2,767.30
41	J-210B	760	3040	0.82	555,493.19	1,065,845.81	2,767.10
42	J-211	487	1948	0.52	552,733.01	1,067,162.98	2,783.40
43	J-212	456	1824	0.49	556,575.36	1,065,953.13	2,779.26
44	J-215	675	2700	0.73	555,851.89	1,061,781.47	2,759.66
45	J-216	358	1432	0.39	557,475.22	1,065,108.81	2,799.87
46	J-217	453	1812	0.49	557,623.00	1,068,603.46	2,788.64
47	J-221	487	1948	0.52	556,626.31	1,066,664.06	2,815.06
48	J-225	498	1992	0.54	554,924.79	1,065,267.42	2,817.63
49	J-23	210	840	0.23	557,173.87	1,068,241.89	2,790.00
50	J-24	134	536	0.14	557,403.40	1,067,652.55	2,797.25
51	J-25	350	1400	0.38	557,551.19	1,066,961.77	2,783.90
52	J-26	250	1000	0.27	558,912.66	1,067,817.49	2,777.46
53	J-27	98	392	0.11	558,215.92	1,068,179.86	2,779.96
54	J-28	67	268	0.07	557,957.66	1,069,075.48	2,826.45
55	J-3	132	528	0.14	553,523.10	1,062,728.34	2,757.57
56	J-30A	1	4	0.00	558,400.47	1,069,338.62	2,782.22
57	J-31	58	232	0.06	559,445.39	1,069,501.72	2,805.20

58	J-33	123	492	0.13	559,448.47	1,068,848.83	2,785.75
59	J-34	78	312	0.08	560,507.42	1,067,915.59	2,739.56
60	J-35	76	304	0.08	558,701.20	1,068,543.13	2,789.84
61	J-36	6	24	0.01	559,895.01	1,068,096.94	2,800.70
62	J-36A	4	16	0.00	560,427.84	1,068,483.91	2,802.36
63	J-37	1	4	0.00	560,535.53	1,068,774.61	2,800.53
64	J-38	6	24	0.01	560,449.41	1,069,279.46	2,805.40
65	J-39	4	16	0.00	560,286.70	1,069,475.64	2,809.98
66	J-4	245	980	0.26	560,217.96	1,070,177.21	2,758.28
67	J-40	5	20	0.01	554,219.99	1,064,539.64	2,801.65
68	J-41	3	12	0.00	560,744.32	1,070,330.22	2,775.00
69	J-46	2	8	0.00	560,925.41	1,069,136.25	2,804.16
70	J-47	8	32	0.01	561,358.52	1,069,004.99	2,808.08
71	J-48	3	12	0.00	561,273.89	1,070,297.42	2,803.64
72	J-50	456	1824	0.49	561,656.03	1,068,874.20	2,777.86
73	J-51	134	536	0.14	555,773.06	1,068,455.14	2,789.30
74	J-52	0	0	0.00	561,974.69	1,068,774.01	2,800.00
75	J-52A	11	44	0.01	562,499.22	1,068,633.20	2,832.32
76	J-53	12	48	0.01	563,599.58	1,067,443.92	2,803.00
77	J-54	123	492	0.13	562,063.14	1,070,126.20	2,826.41
78	J-54A	81	324	0.09	559,770.14	1,072,117.34	2,815.97
79	J-54B	987	3948	1.06	559,870.28	1,072,875.37	2,780.43
80	J-54C	0	0	0.00	560,352.77	1,073,533.79	2,823.59
81	J-54D	1324	5296	1.42	559,233.52	1,073,315.41	2,818.53
82	J-54E	1687	6748	1.82	557,526.73	1,073,164.93	2,778.35
83	J-57	54	216	0.06	559,124.50	1,074,429.95	2,801.19
84	J-58B	8	32	0.01	562,964.68	1,068,373.08	2,809.65
85	J-59	432	1728	0.46	563,569.06	1,068,244.09	2,806.69
86	J-6	453	1812	0.49	562,803.79	1,067,519.31	2,762.40
87	J-60	234	936	0.25	555,162.16	1,067,793.80	2,794.80
88	J-60B	231	924	0.25	562,851.29	1,067,897.14	2,794.60

89	J-65	212	848	0.23	563,167.24	1,067,393.68	2,794.88
90	J-66	0	0	0.00	560,709.46	1,072,139.59	2,802.75
91	J-67	5	20	0.01	561,208.39	1,072,992.22	2,780.87
92	J-7	450	1800	0.48	561,573.53	1,073,418.30	2,763.51
93	J-72	3	12	0.00	555,438.76	1,068,087.36	2,783.40
94	J-s18	543	2172	0.58	561,009.65	1,074,297.35	2,812.00
95	AV-5	457	1828	0.49	563,938.38	1,069,380.58	2,825.00
96	J-167D	89	356	0.10	560,935.41	1,070,430.02	2,795.45
97	J-2	102	408	0.11	561,348.51	1,079,136.95	2,771.11
98	J-3	231	924	0.25	561,283.49	1,063,004.90	2,785.00
99	J-167G	227	908	0.24	561,646.83	1,071,297.62	2,817.00
100	J-5	97	388	0.10	555,763.76	1,068,870.72	2,767.00
101	J-6	0	0	0.00	561,984.66	1,068,855.84	2,824.35
102	J-7	3	12	0.00	562,479.32	1,068,884.21	2,783.22
103	J-8	17	68	0.02	563,589.98	1,068,663.28	2,818.21
104	J-9	76	304	0.08	562,083.04	1,067,683.62	2,803.12
105	J-10	87	348	0.09	559,870.44	1,072,126.52	2,815.13
106	J-11	976	3904	1.05	555,789.07	1,072,347.22	2,737.80
107	J-12	453	1812	0.49	565,508.32	1,072,112.42	2,790.66
108	J-13	569	2276	0.61	565,673.54	1,071,218.33	2,793.04
109	J-14	601	2404	0.65	556,778.06	1,068,137.86	2,789.55
110	J-15	6	24	0.01	565,809.35	1,074,147.95	2,809.68
111	J-16	45	180	0.05	565,938.18	1,069,150.88	2,800.56
112	J-17	23	92	0.02	566,005.41	1,070,160.42	2,799.39
113	J-18	35	140	0.04	566,148.11	1,079,176.75	2,789.97
114	J-19	29	116	0.03	566,283.39	1,063,184.89	2,771.84
115	J-20	167	668	0.18	566,346.23	1,071,197.52	2,817.15
116	J-21	235	940	0.25	556,463.26	1,068,200.62	2,817.87
117	J-23	543	2172	0.58	566,584.06	1,068,215.74	2,818.40
118	J-24	705	2820	0.76	566,679.33	1,068,224.27	2,787.45
119	J-25	567	2268	0.61	566,789.78	1,068,233.58	2,795.05

120	J-26	501	2004	0.54	566,883.34	1,067,243.52	2,828.00
121	J-27	551	2204	0.59	556,970.24	1,072,256.92	2,787.80
122	J-28	472	1888	0.51	557,089.47	1,072,267.22	2,828.80
123	J-29	481	1924	0.52	560,449.41	1,069,279.46	2,827.70
124	J-30	431	1724	0.46	560,586.70	1,069,475.64	2,817.80
125	J-31	445	1780	0.48	560,687.96	1,070,177.51	2,766.66
126	J-32	521	2084	0.56	555,619.99	1,064,539.54	2,771.73
127	J-38	352	1408	0.38	565,744.32	1,070,330.62	2,792.16
128	J-39	342	1368	0.37	565,625.41	1,069,136.95	2,816.00
129	J-40	257	1028	0.28	562,158.52	1,069,004.23	2,833.00
130	J-42	357	1428	0.38	563,173.89	1,070,297.82	2,780.00
131	J-43	542	2168	0.58	564,256.03	1,068,874.22	2,763.73
132	J-46	487	1948	0.52	559,873.06	1,068,455.34	2,758.43
133	J-47	784	3136	0.84	566,974.69	1,068,774.71	2,755.98
134	J-48	452	1808	0.49	564,499.22	1,068,633.52	2,762.10
135	J-49	852	3408	0.92	566,599.58	1,067,443.82	2,751.97
136	J-50	704	2816	0.76	562,863.14	1,070,126.82	2,759.56
137	J-51	456	1824	0.49	559,770.14	1,072,117.64	2,768.69
138	J-52	567	2268	0.61	559,070.28	1,072,875.67	2,790.30
139	J-53	506	2024	0.55	568,952.77	1,073,533.89	2,777.12
140	J-54	480	1920	0.52	558,733.52	1,073,315.76	2,768.00
141	J-56	210	840	0.23	556,726.73	1,073,164.03	2,762.84
142	J-57	156	625	0.17	558,924.50	1,074,429.93	2,769.26
143	J-58	63	252	0.07	562,674.68	1,068,373.98	2,780.74
Sum		47,819	191,277	51.45			

Appendix-II
Pipe Input data

No	Label	Start Node	Stop Node	Length	Diameter (mm)	Material	Hazen-Williams C
1	P-1	J-170	J-s18	1,075	350	DCI	130
2	P-10	J-58B	J-52A	42	150	PVC	150
3	P-100	J-37	J-36A	100	100	PVC	150
4	P-101	J-33	J-163	471	100	PVC	150
5	P-102	J-57	J-60	261	100	PVC	150
6	P-103	J-60	J-59	65	100	PVC	150
7	P-104	J-59	J-159A	273	80	PVC	150
8	P-105	J-37	J-41	131	200	DCI	130
9	P-106	J-41	J-46	100	200	DCI	130
10	P-107	J-46	J-48	28	200	DCI	130
11	P-108	J-48	J-51	235	200	DCI	130
12	P-109	J-17	J-16	180	80	PVC	150
13	P-110	J-123	J-122	538	80	PVC	150
14	P-111	J-122	J-121	200	80	PVC	150
15	P-113	J-105C	J-105	115	350	DCI	130
16	P-114	J-105	J-104	206	300	DCI	130
17	P-115	R-1	PMP-1	45	150	DCI	130
18	P-116	PMP-1	J-174	344	150	DCI	130
19	P-117	R-3	PMP-3	55	150	DCI	130
20	P-118	PMP-3	AV-5	57	150	DCI	130
21	P-119	R-4	PMP-4	65	150	DCI	130
22	P-12	J-65	J-66	243	80	PVC	150
23	P-120	PMP-4	J-162	969	150	PVC	150
24	P-121	R-5	PMP-5	75	150	PVC	150
25	P-122	PMP-5	J-162	73	150	PVC	150
26	P-123	R-6	PMP-6	50	150	PVC	150
27	P-124	PMP-6	J-168	334	150	PVC	150
28	P-125	R-7	PMP-7	86	150	PVC	150
29	P-126	PMP-7	J-170	596	150	PVC	150
30	P-127	R-8	PMP-8	50	150	PVC	150
31	P-128	PMP-8	R-9	810	150	PVC	150
32	P-129	R-9	PMP-9	50	150	PVC	150
33	P-13	J-54B	J-54C	482	90	PVC	150
34	P-130	PMP-9	R-10	337	200	DCI	130
35	P-131	R-10	PMP-10	50	200	DCI	130
36	P-132	PMP-10	T-2	1,500	250	DCI	130
37	P-133	R-2	PMP-2	50	150	PVC	150

38	P-134	PMP-2	J-174	172	150	PVC	150
39	P-14	J-54C	J-54E	561	90	PVC	150
40	P-15	J-54C	J-54D	232	90	PVC	150
41	P-16	J-6	J-4	380	150	PVC	150
42	P-18	J-114	J-113	443	80	PVC	150
43	P-19	J-127A	J-208	630	80	PVC	150
44	P-2	J-105	J-105B	260	150	PVC	150
45	P-20	J-208	J-208A	550	80	PVC	150
46	P-21	J-208A	J-114A	111	150	PVC	150
47	P-29	J-167C	J-167F	220	110	PVC	150
48	P-3	J-115	J-201	53	100	PVC	150
49	P-34	J-217	J-211	728	200	DCI	130
50	P-35	J-211	J-212	590	150	PVC	150
51	P-36	T-1	J-30A	240	350	DCI	130
52	P-4	J-162	J-168	368	200	DCI	130
53	P-40	J-30A	J-38	134	300	DCI	130
54	P-41	J-38	J-39	297	150	DCI	130
55	P-42	J-39	J-40	200	150	DCI	130
56	P-43	J-40	J-47	281	150	DCI	130
57	P-44	J-47	J-53	264	100	PVC	150
58	P-45	J-38	J-37	163	200	DCI	130
59	P-46	J-51	J-52	115	150	PVC	150
60	P-47	J-52	J-57	251	100	PVC	150
61	P-48	J-54	J-18	247	150	PVC	150
62	P-49	J-54A	J-54	236	150	PVC	150
63	P-5	J-174	AV-5	803	200	DCI	130
64	P-50	J-54A	J-54B	454	150	PVC	150
65	P-51	J-54A	J-66	355	80	PVC	150
66	P-52	J-66	J-67	50	80	PVC	150
67	P-53	J-54	J-65	518	100	PVC	150
68	P-54	J-67	J-72	366	80	PVC	150
69	P-59	J-17	J-50	293	150	PVC	150
70	P-6	AV-5	J-s18	746	250	DCI	130
71	P-60	J-50	J-7	215	150	PVC	150
72	P-61	J-7	J-6	476	150	PVC	150
73	P-62	J-24	J-26	74	80	PVC	150
74	P-63	J-26	J-27	236	80	PVC	150
75	P-64	J-26	J-33	486	80	PVC	150
76	P-65	J-21	J-28	317	80	PVC	150
77	P-66	J-162	J-168	350	150	PVC	150
78	P-67	J-105B	J-105A	118	50	PVC	150

79	P-68	J-105B	J-102B	180	150	PVC	150
80	P-69	J-102B	J-104	270	150	PVC	150
81	P-7	J-s18	T-1	1,200	300	DCI	130
82	P-70	J-102B	J-115	153	100	PVC	150
83	P-71	J-115	J-167A	381	100	PVC	150
84	P-72	J-104	J-217	543	300	DCI	130
85	P-73	J-217	J-107	487	300	DCI	130
86	P-74	J-107	J-215	174	100	PVC	150
87	P-75	J-107	J-109	249	200	DCI	130
88	P-76	J-109	J-221	314	200	DCI	130
89	P-77	J-221	J-111	201	200	DCI	130
90	P-78	J-215	J-111	443	100	PVC	130
91	P-79	J-111	J-114	350	200	DCI	130
92	P-80	J-112	J-113	197	100	PVC	150
93	P-81	J-109	J-112	179	100	PVC	150
94	P-82	J-114	J-114A	242	200	DCI	130
95	P-83	J-114A	J-127	392	200	DCI	130
96	P-84	J-168	J-170	390	200	DCI	130
97	P-85	J-127	J-212	322	100	PVC	150
98	P-86	J-127	J-127A	165	200	DCI	130
99	P-87	J-127A	J-225	315	150	DCI	130
100	P-88	J-225	J-123	243	150	DCI	130
101	P-9	J-57	J-58B	275	150	DCI	130
102	P-90	J-120	J-216	347	100	DCI	130
103	P-91	J-225	J-133	430	150	DCI	130
104	P-92	J-121	J-120	142	80	PVC	150
105	P-93	T-2	T-1	607	200	DCI	130
106	P-96	J-31	J-36	248	75	PVC	150
107	P-99	J-36A	J-36	112	80	PVC	150
108	P-1	J-210B	J-54D	157	90	PVC	150
109	P-4	J-27	J-2	285	80	PVC	150
110	P-7	J-3	J-167G	654	75	PVC	150
111	P-8	J-167G	J-5	543	50	DCI	150
112	P-15	J-167A	J-167E	156	150	PVC	150
113	P-16	J-167E	J-167F	234	150	PVC	150
114	P-17	J-216	J-104	245	150	PVC	150
115	P-18	J-216	J-6	115	150	PVC	150
116	P-19	J-6	J-102B	214	50	PVC	150
117	P-20	J-6	J-7	112	50	PVC	150
118	P-21	J-7	J-115	243	80	PVC	150
119	P-22	J-7	J-8	102	150	DCI	130

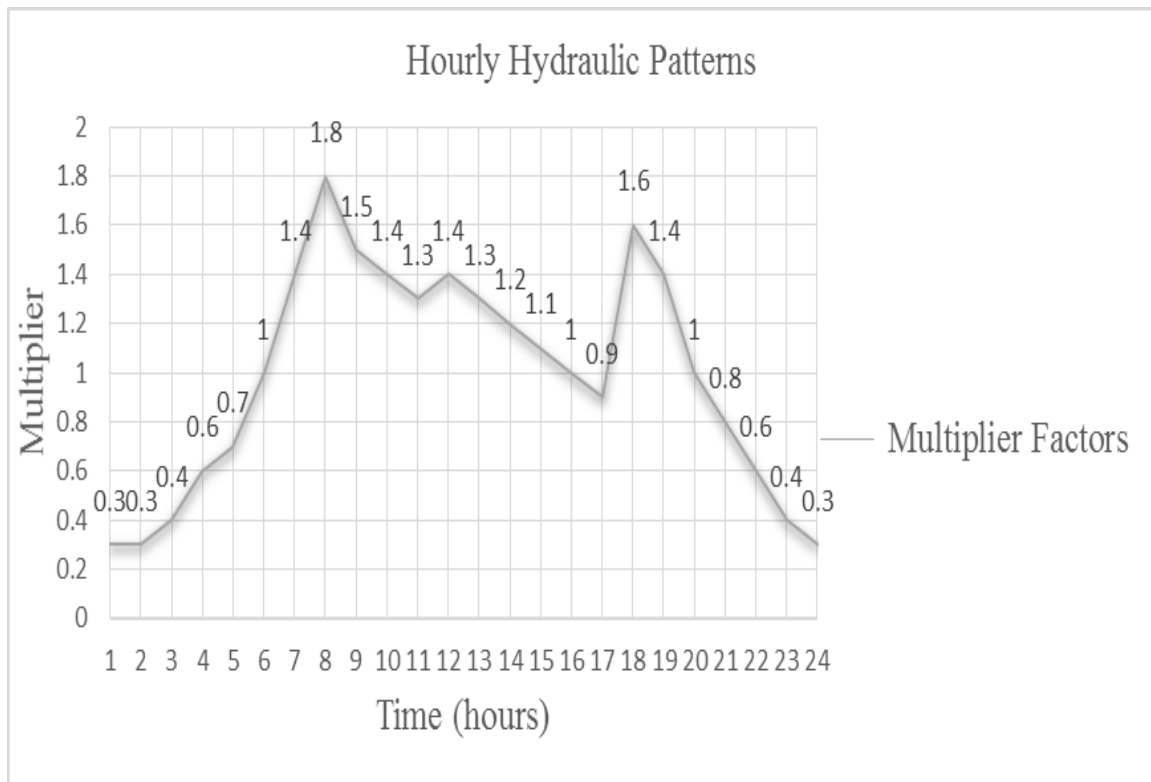
120	P-23	J-8	J-9	106	150	DCI	130
121	P-24	J-9	J-10	169	150	DCI	130
122	P-25	J-10	J-167F	167	75	PVC	150
123	P-26	J-105C	J-105A	186	75	PVC	150
124	P-27	J-105A	J-201	111	75	PVC	150
125	P-28	J-201	J-167C	307	75	PVC	150
126	P-29	J-210	J-210B	195	75	PVC	150
127	P-30	J-54E	J-11	430	75	PVC	150
128	P-31	J-11	J-3	368	75	PVC	150
129	P-32	J-34	J-3	175	150	PVC	150
130	P-33	J-54E	J-18	145	150	PVC	150
131	P-35	J-24	J-12	259	80	PVC	150
132	P-36	J-12	J-25	259	80	PVC	150
133	P-37	J-25	J-163	165	150	PVC	150
134	P-38	J-60B	J-159A	157	150	PVC	150
135	P-39	J-159A	J-35	101	150	PVC	150
136	P-40	J-53	J-58B	138	150	PVC	150
137	P-41	J-47	J-48	147	150	PVC	150
138	P-43	J-36	J-21	155	150	PVC	150
139	P-44	J-21	J-24	134	150	PVC	150
140	P-45	J-12	J-33	191	150	PVC	150
141	P-46	J-167D	J-13	193	150	PVC	150
142	P-47	J-13	J-25	186	150	PVC	150
143	P-49	J-14	J-37	175	150	PVC	150
144	P-50	J-36	J-15	229	150	PVC	150
145	P-52	J-48	J-15	157	150	PVC	150
146	P-53	J-15	J-16	112	150	PVC	150
147	P-55	J-16	J-17	111	50	PVC	150
148	P-56	J-17	J-167D	219	50	PVC	150
149	P-57	J-35	J-18	149	50	PVC	150
150	P-58	J-18	J-34	171	50	PVC	150
151	P-59	J-2	J-19	285	80	PVC	130
152	P-62	T-2	J-20	120	400	DCI	130
153	P-63	J-20	J-105C	159	400	DCI	130
154	P-64	J-109	J-20	176	200	DCI	130
155	P-65	J-133	J-21	155	200	DCI	130
156	P-66	J-21	J-208	135	200	DCI	130
157	P-67	J-54D	J-11	223	200	DCI	130
158	P-68	T-1	J-23	412	150	PVC	150
159	P-69	J-23	J-18	316	150	PVC	150
160	P-70	J-23	J-24	234	200	DCI	130

161	P-71		J-25	212	200	DCI	130
162	P-72	J-25	J-26	356	200	DCI	130
163	P-73	J-26	J-27	217	200	DCI	130
164	P-74	J-27	J-28	187	200	DCI	130
165	P-75	J-28	J-29	169	200	DCI	130
166	P-76	J-29	J-30	121	200	DCI	130
167	P-77	J-30	J-72	194	200	DCI	130
168	P-78	J-210	J-31	250	200	DCI	130
169	P-79	J-31	J-5	196	200	DCI	130
170	P-80	J-210B	J-32	154	200	DCI	130
171	P-81	J-32	J-3	175	200	DCI	130
172	P-98	J-167G	J-114A	115	200	DCI	130
173	P-100	J-123	J-38	416	80	PVC	150
174	P-101	J-38	J-124	416	80	PVC	150
175	P-102	J-127A	J-38	178	80	PVC	150
176	P-103	J-30A	J-39	187	80	PVC	150
177	P-104	J-39	J-40	145	80	PVC	150
178	P-105	J-40	J-28	165	80	PVC	150
179	P-106	J-39	J-14	135	80	PVC	150
180	P-110	J-14	J-31	167	80	PVC	150
181	P-111	J-31	J-40	111	90	PVC	150
182	P-112	J-21	J-23	129	90	PVC	150
183	P-113	J-23	J-17	185	90	PVC	150
184	P-114	J-28	J-42	83	90	PVC	150
185	P-115	J-42	J-43	176	90	PVC	150
186	P-116	J-43	J-17	107	90	PVC	150
187	P-119	J-16	J-46	98	90	PVC	150
188	P-120	J-46	J-47	189	150	DCI	130
189	P-121	J-47	J-48	104	150	DCI	130
190	P-122	J-48	J-49	195	150	DCI	130
191	P-123	J-49	J-50	101	150	DCI	130
192	P-124	J-50	J-3	103	150	DCI	130
193	P-127	J-25	J-51	102	150	DCI	130
194	P-128	J-51	J-18	211	150	DCI	130
195	P-129	J-167D	J-52	150	50	PVC	150
196	P-130	J-52	J-35	143	50	PVC	150
197	P-133	J-42	J-53	137	75	PVC	150
198	P-134	J-53	J-23	162	75	PVC	150
199	P-135	J-23	J-54	145	75	PVC	150
200	P-136	J-54	J-26	102	75	PVC	150
201	P-137	J-4	J-56	284	75	PVC	150

202	P-138	J-56	J-3	284	75	PVC	150
203	P-139	J-19	J-57	285	80	PVC	150
204	P-140	J-57	J-34	285	80	PVC	150
205	P-141	J-56	J-57	152	50	PVC	150
206	P-142	J-57	J-51	148	50	PVC	150
207	P-143	J-51	J-52	142	50	PVC	150
208	P-144	J-52	J-59	232	50	PVC	150
209	P-145	J-52A	J-58	113	100	PVC	150
210	P-146	J-58	J-60B	120	100	PVC	150
211	P-147	J-59	J-58	57	50	PVC	150
212	P-159	J-6	J-47	200	150	PVC	150

Appendix-III

Hourly Demand Hydraulic Multiplier Factor



Appendix-IV

Low Demand Junction out Put Result

ID	Label	Demand (L/s)	Pressure (m H ₂ O)	Pressure Head (m)	Hydraulic Grade (m)
52	J-115	0.18	36.04	36.11	2,793.86
53	J-201	0.16	37.94	38.01	2,791.96
54	J-102B	0.11	35.24	35.31	2,794.69
55	J-104	0.12	33.92	33.99	2,796.01
56	J-105	0.08	13.47	13.5	2,816.50
57	J-105A	0.16	42.5	42.58	2,787.40
58	J-105B	0.22	45.26	45.35	2,784.65
59	J-105C	0.04	8.74	8.76	2,821.24
60	J-107	0.08	37.56	37.63	2,792.37
61	J-109	0.08	14.87	14.9	2,815.10
62	J-111	0.18	39.63	39.71	2,790.32
63	J-112	0.11	11.49	11.52	2,818.49
64	J-113	0.13	30.45	30.51	2,799.50
65	J-114	0.25	51.72	51.83	2,778.24
66	J-114A	0.25	60.26	60.39	2,769.71
68	J-120	0.26	11.51	11.53	2,818.46
69	J-121	0.21	38.83	38.91	2,791.08
70	J-122	0.17	12.75	12.78	2,817.22
71	J-123	0.12	13.67	13.69	2,816.36
72	J-124	0.21	46.89	46.99	2,783.05
73	J-127	0.24	41.9	41.98	2,788.09
74	J-127A	0.23	48.93	49.03	2,781.04
75	J-133	0.3	60.26	60.38	2,769.67
76	J-159A	0.24	47.35	47.44	2,801.42
77	J-16	0.24	105.42	105.63	2,743.00
78	J-162	0.27	66.62	66.76	2,790.44
79	J-163	0.26	60.32	60.44	2,788.30
80	J-167A	0.26	13.98	14.01	2,815.95

82	J-167C	0.22	51.11	51.21	2,778.74
84	J-167E	0.22	51.46	51.56	2,778.39
85	J-167F	0.21	49.7	49.8	2,780.15
87	J-168	0.26	65.56	65.69	2,790.75
88	J-17	0.21	45.93	46.02	2,802.64
89	J-170	0.21	60.6	60.72	2,793.19
90	J-174	0.21	44.4	44.49	2,811.78
91	J-18	0.16	45.83	45.92	2,800.91
92	J-208	0.27	15.78	15.81	2,814.24
93	J-208A	0.22	8.49	8.5	2,821.59
94	J-21	0.04	60.76	60.88	2,787.95
95	J-210	0.34	72.33	72.47	2,767.30
97	J-210B	0.34	73.54	73.69	2,767.10
98	J-211	0.22	46.51	46.6	2,783.40
99	J-212	0.21	50.65	50.75	2,779.26
101	J-215	0.31	70.2	70.34	2,759.66
102	J-216	0.16	30.07	30.13	2,799.87
103	J-217	0.21	41.28	41.36	2,788.64
105	J-221	0.22	14.93	14.96	2,815.06
106	J-225	0.23	12.4	12.43	2,817.63
107	J-23	0.1	58.64	58.76	2,790.00
108	J-24	0.06	51.47	51.57	2,797.25
109	J-25	0.16	64.71	64.84	2,783.90
110	J-26	0.11	71.17	71.31	2,777.46
111	J-27	0.05	68.64	68.78	2,779.96
112	J-28	0.03	22.31	22.35	2,826.45
113	J-3	0.06	90.88	91.06	2,757.57
115	J-30A	0	66.64	66.77	2,782.22
116	J-31	0.03	43.61	43.7	2,805.20
117	J-33	0.05	62.88	63	2,785.75
118	J-34	0.03	108.85	109.07	2,739.56

119	J-35	0.03	58.9	59.02	2,789.84
120	J-36	0	48.08	48.18	2,800.70
121	J-36A	0	46.49	46.58	2,802.36
122	J-37	0	48.33	48.43	2,800.53
123	J-38	0	43.5	43.59	2,805.40
124	J-39	0	38.91	38.99	2,809.98
125	J-4	0.11	90.17	90.35	2,758.28
126	J-40	0	47.21	47.31	2,801.65
127	J-41	0	73.8	73.95	2,775.00
128	J-46	0	44.69	44.78	2,804.16
129	J-47	0	40.78	40.86	2,808.08
130	J-48	0	45.21	45.3	2,803.64
131	J-50	0.21	70.65	70.79	2,777.86
132	J-51	0.06	59.52	59.64	2,789.30
133	J-52	0	48.84	48.94	2,800.00
134	J-52A	0	16.55	16.58	2,832.32
135	J-53	0	45.81	45.9	2,803.00
136	J-54	0.05	20.34	20.39	2,826.41
137	J-54A	0.04	30.71	30.77	2,815.97
138	J-54B	0.45	66.03	66.16	2,780.43
139	J-54C	0	21.43	21.47	2,823.59
140	J-54D	0.6	23.96	24.01	2,818.53
141	J-54E	0.76	68.17	68.31	2,778.35
142	J-57	0.03	47.61	47.71	2,801.19
143	J-58B	0	39.17	39.25	2,809.65
144	J-59	0.2	42.1	42.18	2,806.69
145	J-6	0.21	86.06	86.23	2,762.40
146	J-60	0.1	53.97	54.08	2,794.80
147	J-60B	0.1	54.15	54.26	2,794.60
148	J-65	0.1	51.85	51.95	2,794.88
149	J-66	0	44.06	44.15	2,802.75

150	J-67	0	65.96	66.09	2,780.87
151	J-7	0.21	84.96	85.13	2,763.51
152	J-72	0	63.9	64.03	2,783.40
153	J-s18	0.25	41.21	41.3	2,812.00
176	AV-5	0.21	29.7	29.76	2,825.00
302	J-167D	0.04	53.18	53.29	2,795.45
305	J-2	0.05	77.45	77.6	2,771.11
308	J-3	0.1	55.64	55.76	2,785.00
310	J-167G	0.1	13.12	13.14	2,817.00
312	J-5	0.04	72.61	72.76	2,767.00
326	J-6	0	5.64	5.65	2,824.35
329	J-7	0	46.65	46.75	2,783.22
332	J-8	0.01	11.73	11.76	2,818.21
334	J-9	0.03	26.79	26.85	2,803.12
336	J-10	0.04	14.81	14.84	2,815.13
343	J-11	0.44	104.53	104.74	2,737.80
349	J-12	0.21	57.98	58.09	2,790.66
361	J-13	0.26	55.59	55.7	2,793.04
364	J-14	0.27	59.28	59.4	2,789.55
367	J-15	0	39.15	39.23	2,809.68
371	J-16	0.02	48.25	48.35	2,800.56
374	J-17	0.01	49.36	49.46	2,799.39
377	J-18	0.02	58.65	58.77	2,789.97
380	J-19	0.01	76.69	76.84	2,771.84
384	J-20	0.08	12.82	12.85	2,817.15
388	J-21	0.1	12.16	12.18	2,817.87
393	J-23	0.25	29.05	29.11	2,818.40
396	J-24	0.32	59.92	60.04	2,787.45
398	J-25	0.26	52.32	52.42	2,795.05
400	J-26	0.23	19.42	19.46	2,828.00
402	J-27	0.25	59.53	59.65	2,787.80

404	J-28	0.21	18.6	18.64	2,828.80
406	J-29	0.22	19.69	19.73	2,827.70
408	J-30	0.2	29.57	29.63	2,817.80
411	J-31	0.2	72.96	73.1	2,766.66
414	J-32	0.24	68.9	69.04	2,771.73
440	J-38	0.16	37.82	37.89	2,792.16
444	J-39	0.16	32.88	32.95	2,816.00
446	J-40	0.12	15.86	15.9	2,833.00
458	J-42	0.16	68.62	68.76	2,780.00
460	J-43	0.25	84.79	84.96	2,763.73
467	J-46	0.22	90.02	90.2	2,758.43
469	J-47	0.36	92.46	92.65	2,755.98
471	J-48	0.21	86.35	86.53	2,762.10
473	J-49	0.39	96.46	96.66	2,751.97
475	J-50	0.32	88.89	89.07	2,759.56
481	J-51	0.21	79.89	80.05	2,768.69
484	J-52	0.26	58.35	58.47	2,790.30
490	J-53	0.23	71.49	71.63	2,777.12
493	J-54	0.22	80.6	80.76	2,768.00
497	J-56	0.1	85.62	85.79	2,762.84
500	J-57	0.07	79.24	79.4	2,769.26
507	J-58	0.03	68	68.14	2,780.74

Appendix-V
Low Demand Pipe out Put Result

ID	Label	Diameter (mm)	Material	Hazen- Williams C	Flow (L/s)	Velocity (m/s)	Head loss Gradient (m/km)
154	P-1	350	DCI	130	40.51	0.42	0.569
155	P-10	150	PVC	150	0.94	0.05	0.021
156	P-100	100	PVC	150	0.93	0.12	0.179
157	P-101	100	PVC	150	0.34	0.04	0.028
158	P-102	100	PVC	150	0.66	0.08	0.095
159	P-103	100	PVC	150	0.55	0.07	0.069
160	P-104	80	PVC	150	0.23	0.05	0.039
161	P-105	200	DCI	130	3.02	0.1	0.07
162	P-106	200	DCI	130	3.02	0.1	0.071
163	P-107	200	DCI	130	3.02	0.1	0.074
164	P-108	200	DCI	130	0.87	0.03	0.006
165	P-109	80	PVC	150	0.51	0.1	0.177
167	P-110	80	PVC	150	0.38	0.08	0.103
168	P-111	80	PVC	150	0.22	0.04	0.036
170	P-113	350	DCI	130	0.74	0.01	0
171	P-114	300	DCI	130	0.03	0	0
172	P-115	150	DCI	130	10.65	0.6	2.97
173	P-116	150	DCI	130	10.65	0.6	2.972
174	P-117	150	DCI	130	15.15	0.86	5.704
175	P-118	150	DCI	130	15.15	0.86	5.708
177	P-119	150	DCI	130	15.2	0.86	5.738
178	P-12	80	PVC	150	-0.65	0.13	0.276
179	P-120	150	PVC	150	15.2	0.86	4.403
180	P-121	150	PVC	150	14.07	0.8	3.818
181	P-122	150	PVC	150	14.07	0.8	3.821
182	P-123	150	PVC	150	5.87	0.33	0.756
183	P-124	150	PVC	150	5.87	0.33	0.756

184	P-125	150	PVC	150	6.11	0.35	0.813
185	P-126	150	PVC	150	6.11	0.35	0.815
186	P-127	150	PVC	150	28.71	1.62	14.299
187	P-128	150	PVC	150	28.71	1.62	14.301
188	P-129	150	PVC	150	29.87	1.69	15.395
189	P-13	90	PVC	150	3.33	0.52	3.178
190	P-130	200	DCI	130	29.87	0.95	4.943
191	P-131	200	DCI	130	14.76	0.47	1.339
192	P-132	250	DCI	130	14.76	0.3	0.452
193	P-133	150	PVC	150	7.27	0.41	1.125
194	P-134	150	PVC	150	7.27	0.41	1.125
195	P-14	90	PVC	150	-3.13	0.49	2.842
196	P-15	90	PVC	150	6.46	1.01	10.861
197	P-16	150	PVC	150	0.1	0.01	0
199	P-18	80	PVC	150	0.42	0.08	0.124
200	P-19	80	PVC	150	0.15	0.03	0.019
201	P-2	150	PVC	150	0.64	0.04	0.013
202	P-20	80	PVC	150	-0.32	0.06	0.073
203	P-21	150	PVC	150	-0.54	0.03	0.008
211	P-29	110	PVC	150	0.01	0	0
212	P-3	100	PVC	150	0.1	0.01	0
217	P-34	200	DCI	130	-0.5	0.02	0.002
218	P-35	150	PVC	150	-0.73	0.04	0.016
219	P-36	350	DCI	130	7.11	0.07	0.022
223	P-4	200	DCI	130	18.64	0.59	2.063
224	P-40	300	DCI	130	6.47	0.09	0.04
225	P-41	150	DCI	130	1.32	0.07	0.063
226	P-42	150	DCI	130	1.32	0.07	0.061
227	P-43	150	DCI	130	1.32	0.07	0.062
228	P-44	100	PVC	150	0.82	0.1	0.142
229	P-45	200	DCI	130	5.15	0.16	0.192

230	P-46	150	PVC	150	0.81	0.05	0.021
231	P-47	100	PVC	150	0.81	0.1	0.139
232	P-48	150	PVC	150	-2.48	0.14	0.153
233	P-49	150	PVC	150	-2.98	0.17	0.216
234	P-5	200	DCI	130	17.71	0.56	1.877
235	P-50	150	PVC	150	3.77	0.21	0.334
236	P-51	80	PVC	150	-0.83	0.17	0.433
237	P-52	80	PVC	150	-1.48	0.3	1.268
238	P-53	100	PVC	150	-0.56	0.07	0.07
239	P-54	80	PVC	150	-1.49	0.3	1.272
244	P-59	150	PVC	150	1.32	0.07	0.048
245	P-6	250	DCI	130	32.66	0.67	1.965
246	P-60	150	PVC	150	1.11	0.06	0.035
247	P-61	150	PVC	150	0.9	0.05	0.024
248	P-62	80	PVC	150	1.09	0.22	0.712
249	P-63	80	PVC	150	0.43	0.09	0.126
250	P-64	80	PVC	150	0.22	0.04	0.037
251	P-65	80	PVC	150	0.38	0.08	0.1
252	P-66	150	PVC	150	10.37	0.59	2.169
253	P-67	50	PVC	150	0.13	0.06	0.134
254	P-68	150	PVC	150	0.29	0.02	0.003
255	P-69	150	PVC	150	-0.68	0.04	0.014
256	P-7	300	DCI	130	72.92	1.03	3.581
257	P-70	100	PVC	150	0.87	0.11	0.16
258	P-71	100	PVC	150	0.44	0.06	0.044
259	P-72	300	DCI	130	-1.39	0.02	0.002
260	P-73	300	DCI	130	-1.09	0.02	0.001
261	P-74	100	PVC	150	-0.17	0.02	0.009
262	P-75	200	DCI	130	-1	0.03	0.01
263	P-76	200	DCI	130	-2.57	0.08	0.053
264	P-77	200	DCI	130	-2.8	0.09	0.061

265	P-78	100	PVC	130	-0.47	0.06	0.067
266	P-79	200	DCI	130	-3.46	0.11	0.091
268	P-80	100	PVC	150	-0.3	0.04	0.023
269	P-81	100	PVC	150	-0.18	0.02	0.008
270	P-82	200	DCI	130	-4.13	0.13	0.127
271	P-83	200	DCI	130	2.86	0.09	0.064
272	P-84	200	DCI	130	34.61	1.1	6.49
273	P-85	100	PVC	150	0.93	0.12	0.181
274	P-86	200	DCI	130	1.69	0.05	0.025
275	P-87	150	DCI	130	0.97	0.05	0.035
276	P-88	150	DCI	130	0.54	0.03	0.011
278	P-9	150	DCI	130	0.13	0.01	0.001
279	P-90	100	DCI	130	-0.25	0.03	0.021
280	P-91	150	DCI	130	0.21	0.01	0.002
281	P-92	80	PVC	150	0.01	0	0
282	P-93	200	DCI	130	-80.94	2.58	31.301
285	P-96	75	PVC	150	0.29	0.07	0.085
288	P-99	80	PVC	150	0.93	0.18	0.529
291	P-1	90	PVC	150	-6.56	1.03	11.182
306	P-4	80	PVC	150	0.38	0.08	0.102
311	P-7	75	PVC	150	5.78	1.31	21.495
313	P-8	50	DCI	150	-2.1	1.07	23.751
323	P-15	150	PVC	150	0.17	0.01	0.002
324	P-16	150	PVC	150	-0.05	0	0
325	P-17	150	PVC	150	-0.62	0.03	0.012
327	P-18	150	PVC	150	0.2	0.01	0
328	P-19	50	PVC	150	0.02	0.01	0.004
330	P-20	50	PVC	150	0.18	0.09	0.263
331	P-21	80	PVC	150	-0.15	0.03	0.017
333	P-22	150	DCI	130	0.33	0.02	0.006
335	P-23	150	DCI	130	0.33	0.02	0.006

337	P-24	150	DCI	130	0.29	0.02	0.004
338	P-25	75	PVC	150	0.25	0.06	0.066
339	P-26	75	PVC	150	0.32	0.07	0.102
340	P-27	75	PVC	150	0.29	0.07	0.083
341	P-28	75	PVC	150	0.23	0.05	0.055
342	P-29	75	PVC	150	-2.68	0.61	5.191
344	P-30	75	PVC	150	3.73	0.84	9.564
345	P-31	75	PVC	150	2.59	0.59	4.853
346	P-32	150	PVC	150	0.63	0.04	0.012
347	P-33	150	PVC	150	-7.63	0.43	1.228
350	P-35	80	PVC	150	0.65	0.13	0.271
351	P-36	80	PVC	150	0.26	0.05	0.052
352	P-37	150	PVC	150	-0.08	0	0
353	P-38	150	PVC	150	0.68	0.04	0.013
354	P-39	150	PVC	150	0.68	0.04	0.015
355	P-40	150	PVC	150	0.82	0.05	0.019
356	P-41	150	PVC	150	0.49	0.03	0.008
358	P-43	150	PVC	150	3.56	0.2	0.301
359	P-44	150	PVC	150	1.79	0.1	0.084
360	P-45	150	PVC	150	0.18	0.01	0.002
362	P-46	150	PVC	150	0.37	0.02	0.005
363	P-47	150	PVC	150	0.11	0.01	0
366	P-49	150	PVC	150	-1.2	0.07	0.039
368	P-50	150	PVC	150	-2.35	0.13	0.138
370	P-52	150	PVC	150	2.65	0.15	0.173
372	P-53	150	PVC	150	0.29	0.02	0.003
375	P-55	50	PVC	150	0.27	0.14	0.542
376	P-56	50	PVC	150	0.26	0.13	0.511
378	P-57	50	PVC	150	0.34	0.17	0.808
379	P-58	50	PVC	150	0.29	0.15	0.62
381	P-59	80	PVC	130	0.33	0.07	0.104

385	P-62	400	DCI	130	-0.5	0	0
386	P-63	400	DCI	130	1.1	0.01	0
387	P-64	200	DCI	130	1.67	0.05	0.024
389	P-65	200	DCI	130	-0.09	0	0
390	P-66	200	DCI	130	-0.2	0.01	0
391	P-67	200	DCI	130	-0.7	0.02	0.005
394	P-68	150	PVC	150	13.68	0.77	3.625
395	P-69	150	PVC	150	10.27	0.58	2.13
397	P-70	200	DCI	130	3.17	0.1	0.078
399	P-71	200	DCI	130	2.85	0.09	0.063
401	P-72	200	DCI	130	2.59	0.08	0.054
403	P-73	200	DCI	130	2.37	0.08	0.045
405	P-74	200	DCI	130	2.12	0.07	0.037
407	P-75	200	DCI	130	1.9	0.06	0.03
409	P-76	200	DCI	130	1.69	0.05	0.025
410	P-77	200	DCI	130	1.49	0.05	0.018
412	P-78	200	DCI	130	2.34	0.07	0.045
413	P-79	200	DCI	130	2.14	0.07	0.036
415	P-80	200	DCI	130	3.53	0.11	0.095
416	P-81	200	DCI	130	3.3	0.1	0.083
438	P-98	200	DCI	130	7.77	0.25	0.409
441	P-100	80	PVC	150	0.03	0.01	0.001
442	P-101	80	PVC	150	0.21	0.04	0.032
443	P-102	80	PVC	150	0.33	0.07	0.08
445	P-103	80	PVC	150	0.64	0.13	0.266
447	P-104	80	PVC	150	0.72	0.14	0.335
448	P-105	80	PVC	150	0.96	0.19	0.57
449	P-106	80	PVC	150	-0.25	0.05	0.046
454	P-110	80	PVC	150	0.67	0.13	0.294
455	P-111	90	PVC	150	0.36	0.06	0.051
456	P-112	90	PVC	150	1.35	0.21	0.598

457	P-113	90	PVC	150	1.23	0.19	0.502
459	P-114	90	PVC	150	1.31	0.21	0.567
461	P-115	90	PVC	150	1.05	0.17	0.377
462	P-116	90	PVC	150	0.81	0.13	0.231
468	P-119	90	PVC	150	0.28	0.04	0.03
470	P-120	150	DCI	130	0.05	0	0
472	P-121	150	DCI	130	0.3	0.02	0.006
474	P-122	150	DCI	130	0.09	0.01	0
476	P-123	150	DCI	130	-0.29	0.02	0.003
477	P-124	150	DCI	130	-0.61	0.03	0.017
482	P-127	150	DCI	130	0.29	0.02	0.003
483	P-128	150	DCI	130	-0.03	0	0
485	P-129	50	PVC	150	-0.14	0.07	0.167
486	P-130	50	PVC	150	-0.3	0.15	0.66
491	P-133	75	PVC	150	0.1	0.02	0.011
492	P-134	75	PVC	150	-0.14	0.03	0.02
494	P-135	75	PVC	150	-0.11	0.03	0.014
495	P-136	75	PVC	150	-0.33	0.07	0.108
498	P-137	75	PVC	150	-0.01	0	0
499	P-138	75	PVC	150	0.04	0.01	0.002
501	P-139	80	PVC	150	0.32	0.06	0.075
502	P-140	80	PVC	150	0.37	0.07	0.095
503	P-141	50	PVC	150	-0.15	0.08	0.188
504	P-142	50	PVC	150	-0.27	0.14	0.533
505	P-143	50	PVC	150	-0.15	0.08	0.184
506	P-144	50	PVC	150	-0.25	0.13	0.459
508	P-145	100	PVC	150	0.94	0.12	0.184
509	P-146	100	PVC	150	0.79	0.1	0.131
510	P-147	50	PVC	150	-0.12	0.06	0.125
527	P-159	150	PVC	150	0.6	0.03	0.01

Appendix-VI

Peak demand Junction Output Result

ID	Label	Demand (L/s)	Pressure (m H ₂ O)	Pressure Head (m)	Hydraulic Grade (m)
52	J-115	1.11	35.14	35.22	2,793.86
53	J-201	0.96	37.04	37.11	2,791.96
54	J-102B	0.68	34.98	35.05	2,794.69
55	J-104	0.71	33.74	33.81	2,796.01
56	J-105	0.45	13.37	13.40	2,816.50
57	J-105A	0.96	41.87	41.95	2,787.40
58	J-105B	1.34	45.03	45.12	2,784.65
59	J-105C	0.23	8.67	8.69	2,821.24
60	J-107	0.5	37.29	37.37	2,792.37
61	J-109	0.48	14.6	14.63	2,815.10
62	J-111	1.11	38.85	38.92	2,790.32
63	J-112	0.68	10.99	11.01	2,818.49
64	J-113	0.76	29.79	29.85	2,799.50
65	J-114	1.49	50.6	50.70	2,778.24
66	J-114A	1.49	58.91	59.03	2,769.71
68	J-120	1.56	10.2	10.22	2,818.46
69	J-121	1.23	37.2	37.28	2,791.08
70	J-122	1.01	11.04	11.06	2,817.22
71	J-123	0.73	11.92	11.94	2,816.36
72	J-124	1.23	44.73	44.82	2,783.05
73	J-127	1.44	40.45	40.53	2,788.09
74	J-127A	1.39	47.4	47.50	2,781.04
75	J-133	1.79	58.47	58.59	2,769.67
76	J-159A	1.41	43.65	43.74	2,801.42
77	J-16	1.41	95.66	95.85	2,743.00
78	J-162	1.61	65.56	65.69	2,790.44
79	J-163	1.56	53.39	53.50	2,788.30
80	J-167A	1.59	12.63	12.66	2,815.95

82	J-167C	1.34	49.76	49.86	2,778.74
84	J-167E	1.34	50.11	50.21	2,778.39
85	J-167F	1.26	48.35	48.45	2,780.15
87	J-168	1.56	64.54	64.67	2,790.75
88	J-17	1.23	37.01	37.09	2,802.64
89	J-170	1.23	59.86	59.98	2,793.19
90	J-174	1.29	43.45	43.54	2,811.78
91	J-18	0.96	37.13	37.20	2,800.91
92	J-208	1.64	13.99	14.02	2,814.24
93	J-208A	1.34	7.12	7.14	2,821.59
94	J-21	0.25	56.36	56.48	2,787.95
95	J-210	2.04	60.34	60.46	2,767.30
97	J-210B	2.07	61.7	61.83	2,767.10
98	J-211	1.34	46.07	46.16	2,783.40
99	J-212	1.23	49.91	50.01	2,779.26
101	J-215	1.84	69.64	69.78	2,759.66
102	J-216	0.98	29.73	29.79	2,799.87
103	J-217	1.23	41.03	41.11	2,788.64
105	J-221	1.34	14.32	14.35	2,815.06
106	J-225	1.36	10.67	10.69	2,817.63
107	J-23	0.58	52.19	52.30	2,790.00
108	J-24	0.35	46.77	46.86	2,797.25
109	J-25	0.96	57.78	57.90	2,783.90
110	J-26	0.68	65.06	65.19	2,777.46
111	J-27	0.28	61.75	61.87	2,779.96
112	J-28	0.18	17.06	17.09	2,826.45
113	J-3	0.35	81.07	81.24	2,757.57
115	J-30A	0	66.5	66.63	2,782.22
116	J-31	0.15	41.01	41.09	2,805.20
117	J-33	0.33	56.3	56.41	2,785.75
118	J-34	0.2	99.1	99.30	2,739.56

119	J-35	0.2	55.17	55.28	2,789.84
120	J-36	0.03	44.92	45.01	2,800.70
121	J-36A	0	44.9	44.99	2,802.36
122	J-37	0	47.22	47.31	2,800.53
123	J-38	0.03	43.21	43.30	2,805.40
124	J-39	0	38.13	38.21	2,809.98
125	J-4	0.66	80.38	80.54	2,758.28
126	J-40	0.03	46.1	46.20	2,801.65
127	J-41	0	72.44	72.59	2,775.00
128	J-46	0	43.14	43.23	2,804.16
129	J-47	0.03	39.21	39.29	2,808.08
130	J-48	0	43.61	43.70	2,803.64
131	J-50	1.23	61.36	61.48	2,777.86
132	J-51	0.35	57.87	57.99	2,789.30
133	J-52	0	47.13	47.23	2,800.00
134	J-52A	0	13.88	13.91	2,832.32
135	J-53	0.03	43.24	43.33	2,803.00
136	J-54	0.33	11.5	11.53	2,826.41
137	J-54A	0.23	21.74	21.79	2,815.97
138	J-54B	2.7	56.72	56.83	2,780.43
139	J-54C	0	11.03	11.05	2,823.59
140	J-54D	3.6	11.64	11.66	2,818.53
141	J-54E	4.59	59.09	59.21	2,778.35
142	J-57	0.15	44.98	45.07	2,801.19
143	J-58B	0.03	36.53	36.61	2,809.65
144	J-59	1.18	38.69	38.77	2,806.69
145	J-6	1.23	76.27	76.43	2,762.40
146	J-60	0.63	50.68	50.78	2,794.80
147	J-60B	0.63	50.52	50.62	2,794.60
148	J-65	0.58	43.01	43.10	2,794.88
149	J-66	0	35.37	35.44	2,802.75

150	J-67	0.03	57.39	57.50	2,780.87
151	J-7	1.23	75.48	75.63	2,763.51
152	J-72	0	56.24	56.35	2,783.40
153	J-s18	1.49	40.56	40.64	2,812.00
176	AV-5	1.23	28.9	28.96	2,825.00
302	J-167D	0.25	46.28	46.38	2,795.45
305	J-2	0.28	69.78	69.92	2,771.11
308	J-3	0.63	43.84	43.93	2,785.00
310	J-167G	0.63	11.72	11.74	2,817.00
312	J-5	0.25	60.64	60.76	2,767.00
326	J-6	0	5.3	5.31	2,824.35
329	J-7	0	45.63	45.72	2,783.22
332	J-8	0.05	10.7	10.72	2,818.21
334	J-9	0.2	25.74	25.80	2,803.12
336	J-10	0.23	13.74	13.77	2,815.13
343	J-11	2.65	92.2	92.39	2,737.80
349	J-12	1.23	51.41	51.51	2,790.66
361	J-13	1.54	48.66	48.76	2,793.04
364	J-14	1.64	57.98	58.10	2,789.55
367	J-15	0.03	36.83	36.91	2,809.68
371	J-16	0.13	45.92	46.02	2,800.56
374	J-17	0.05	45.43	45.53	2,799.39
377	J-18	0.1	51.71	51.82	2,789.97
380	J-19	0.08	68.23	68.36	2,771.84
384	J-20	0.45	12.78	12.81	2,817.15
388	J-21	0.63	10.37	10.39	2,817.87
393	J-23	1.49	22.11	22.16	2,818.40
396	J-24	1.92	52.76	52.87	2,787.45
398	J-25	1.54	45.02	45.11	2,795.05
400	J-26	1.36	11.93	11.96	2,828.00
402	J-27	1.49	51.96	52.06	2,787.80

404	J-28	1.29	10.99	11.01	2,828.80
406	J-29	1.31	12.05	12.08	2,827.70
408	J-30	1.18	21.92	21.96	2,817.80
411	J-31	1.21	60.98	61.10	2,766.66
414	J-32	1.41	57.08	57.20	2,771.73
440	J-38	0.96	36.01	36.08	2,792.16
444	J-39	0.98	31.42	31.48	2,816.00
446	J-40	0.71	13.11	13.14	2,833.00
458	J-42	0.98	62.12	62.24	2,780.00
460	J-43	1.49	76.52	76.68	2,763.73
467	J-46	1.34	80.17	80.34	2,758.43
469	J-47	2.14	82.62	82.79	2,755.98
471	J-48	1.23	76.5	76.65	2,762.10
473	J-49	2.32	86.61	86.78	2,751.97
475	J-50	1.92	79.04	79.20	2,759.56
481	J-51	1.23	72.95	73.10	2,768.69
484	J-52	1.54	52.11	52.21	2,790.30
490	J-53	1.39	64.95	65.08	2,777.12
493	J-54	1.31	74.2	74.35	2,768.00
497	J-56	0.58	75.83	75.99	2,762.84
500	J-57	0.43	70.21	70.35	2,769.26
507	J-58	0.18	64.78	64.92	2,780.74

Appendix-VII
Peak Demand Pipe out Put Result

ID	Label	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Head loss Gradient (m/km)
154	P-1	350	DCI	130	37.40	0.39	0.491
155	P-10	150	PVC	150	5.64	0.32	0.702
156	P-100	100	PVC	150	5.57	0.71	4.938
157	P-101	100	PVC	150	2.04	0.26	0.772
158	P-102	100	PVC	150	3.94	0.5	2.609
159	P-103	100	PVC	150	3.31	0.42	1.891
160	P-104	80	PVC	150	1.37	0.27	1.099
161	P-105	200	DCI	130	18.14	0.58	1.963
162	P-106	200	DCI	130	18.14	0.58	1.962
163	P-107	200	DCI	130	18.14	0.58	1.956
164	P-108	200	DCI	130	5.22	0.17	0.195
165	P-109	80	PVC	150	3.07	0.61	4.863
167	P-110	80	PVC	150	0.23	0.04	0.038
168	P-111	80	PVC	150	-0.78	0.16	0.387
170	P-113	350	DCI	130	27.08	0.28	0.269
171	P-114	300	DCI	130	21.95	0.31	0.389
172	P-115	150	DCI	130	10.73	0.61	3.01
173	P-116	150	DCI	130	10.73	0.61	3.012
174	P-117	150	DCI	130	15.24	0.86	5.769
175	P-118	150	DCI	130	15.24	0.86	5.77
177	P-119	150	DCI	130	15.31	0.87	5.82
178	P-12	80	PVC	150	-1.2	0.24	0.851
179	P-120	150	PVC	150	15.31	0.87	4.465
180	P-121	150	PVC	150	14.34	0.81	3.957
181	P-122	150	PVC	150	14.34	0.81	3.959
182	P-123	150	PVC	150	5.98	0.34	0.78
183	P-124	150	PVC	150	5.98	0.34	0.782
184	P-125	150	PVC	150	6.18	0.35	0.834

185	P-126	150	PVC	150	6.18	0.35	0.833
186	P-127	150	PVC	150	28.71	1.62	14.299
187	P-128	150	PVC	150	28.71	1.62	14.301
188	P-129	150	PVC	150	29.87	1.69	15.395
189	P-13	90	PVC	150	4.44	0.7	5.436
190	P-130	200	DCI	130	29.87	0.95	4.943
191	P-131	200	DCI	130	14.76	0.47	1.339
192	P-132	250	DCI	130	14.76	0.3	0.452
193	P-133	150	PVC	150	7.34	0.42	1.143
194	P-134	150	PVC	150	7.34	0.42	1.144
195	P-14	90	PVC	150	-4.34	0.68	5.198
196	P-15	90	PVC	150	8.78	1.38	19.192
197	P-16	150	PVC	150	0.58	0.03	0.01
199	P-18	80	PVC	150	-1.25	0.25	0.926
200	P-19	80	PVC	150	0.83	0.17	0.436
201	P-2	150	PVC	150	4.68	0.26	0.497
202	P-20	80	PVC	150	-1.19	0.24	0.845
203	P-21	150	PVC	150	-2.53	0.14	0.158
211	P-29	110	PVC	150	0.05	0.01	0.001
212	P-3	100	PVC	150	0.52	0.07	0.062
217	P-34	200	DCI	130	6.01	0.19	0.253
218	P-35	150	PVC	150	4.67	0.26	0.496
219	P-36	350	DCI	130	42.66	0.44	0.626
223	P-4	200	DCI	130	18.02	0.57	1.937
224	P-40	300	DCI	130	38.83	0.55	1.115
225	P-41	150	DCI	130	7.92	0.45	1.718
226	P-42	150	DCI	130	7.92	0.45	1.717
227	P-43	150	DCI	130	7.9	0.45	1.708
228	P-44	100	PVC	150	4.92	0.63	3.926
229	P-45	200	DCI	130	30.88	0.98	5.256
230	P-46	150	PVC	150	4.86	0.28	0.536

231	P-47	100	PVC	150	4.86	0.62	3.849
232	P-48	150	PVC	150	-5.62	0.32	0.699
233	P-49	150	PVC	150	-5.91	0.33	0.767
234	P-5	200	DCI	130	16.78	0.53	1.699
235	P-50	150	PVC	150	7.14	0.4	1.087
236	P-51	80	PVC	150	-1.45	0.29	1.216
237	P-52	80	PVC	150	-2.65	0.53	3.703
238	P-53	100	PVC	150	-0.62	0.08	0.084
239	P-54	80	PVC	150	-2.67	0.53	3.769
244	P-59	150	PVC	150	7.9	0.45	1.309
245	P-6	250	DCI	130	30.79	0.63	1.762
246	P-60	150	PVC	150	6.66	0.38	0.957
247	P-61	150	PVC	150	5.43	0.31	0.654
248	P-62	80	PVC	150	6.54	1.3	19.722
249	P-63	80	PVC	150	2.56	0.51	3.486
250	P-64	80	PVC	150	1.31	0.26	1.008
251	P-65	80	PVC	150	2.27	0.45	2.777
252	P-66	150	PVC	150	10.02	0.57	2.037
253	P-67	50	PVC	150	0.75	0.38	3.537
254	P-68	150	PVC	150	2.59	0.15	0.165
255	P-69	150	PVC	150	-3.52	0.2	0.292
256	P-7	300	DCI	130	66.71	0.94	3.036
257	P-70	100	PVC	150	5.2	0.66	4.358
258	P-71	100	PVC	150	2.63	0.33	1.232
259	P-72	300	DCI	130	12.35	0.17	0.133
260	P-73	300	DCI	130	5.11	0.07	0.026
261	P-74	100	PVC	150	3.14	0.4	1.714
262	P-75	200	DCI	130	1.46	0.05	0.018
263	P-76	200	DCI	130	12.75	0.41	1.021
264	P-77	200	DCI	130	11.41	0.36	0.831
265	P-78	100	PVC	130	1.3	0.17	0.437

266	P-79	200	DCI	130	11.6	0.37	0.858
268	P-80	100	PVC	150	2.01	0.26	0.749
269	P-81	100	PVC	150	2.69	0.34	1.285
270	P-82	200	DCI	130	11.37	0.36	0.827
271	P-83	200	DCI	130	6.76	0.22	0.315
272	P-84	200	DCI	130	32.45	1.03	5.762
273	P-85	100	PVC	150	-3.44	0.44	2.024
274	P-86	200	DCI	130	8.76	0.28	0.509
275	P-87	150	DCI	130	4.82	0.27	0.684
276	P-88	150	DCI	130	1.43	0.08	0.072
278	P-9	150	DCI	130	0.77	0.04	0.023
279	P-90	100	DCI	130	-3.58	0.46	2.844
280	P-91	150	DCI	130	2.03	0.11	0.138
281	P-92	80	PVC	150	-2.02	0.4	2.235
282	P-93	200	DCI	130	-80.94	2.58	31.301
285	P-96	75	PVC	150	1.75	0.4	2.36
288	P-99	80	PVC	150	5.57	1.11	14.646
291	P-1	90	PVC	150	-5.5	0.86	8.059
306	P-4	80	PVC	150	2.29	0.45	2.82
311	P-7	75	PVC	150	0.64	0.15	0.37
313	P-8	50	DCI	150	0.61	0.31	2.425
323	P-15	150	PVC	150	1.04	0.06	0.031
324	P-16	150	PVC	150	-0.29	0.02	0.003
325	P-17	150	PVC	150	-5.37	0.3	0.641
327	P-18	150	PVC	150	0.81	0.05	0.021
328	P-19	50	PVC	150	-0.22	0.11	0.377
330	P-20	50	PVC	150	1.04	0.53	6.424
331	P-21	80	PVC	150	-0.94	0.19	0.549
333	P-22	150	DCI	130	1.98	0.11	0.131
335	P-23	150	DCI	130	1.93	0.11	0.126
337	P-24	150	DCI	130	1.73	0.1	0.102

338	P-25	75	PVC	150	1.5	0.34	1.773
339	P-26	75	PVC	150	2.03	0.46	3.105
340	P-27	75	PVC	150	1.83	0.41	2.545
341	P-28	75	PVC	150	1.39	0.31	1.531
342	P-29	75	PVC	150	-2.89	0.65	5.959
344	P-30	75	PVC	150	5.11	1.16	17.135
345	P-31	75	PVC	150	2.15	0.49	3.437
346	P-32	150	PVC	150	3.76	0.21	0.332
347	P-33	150	PVC	150	-14.04	0.79	3.802
350	P-35	80	PVC	150	3.88	0.77	7.503
351	P-36	80	PVC	150	1.59	0.32	1.432
352	P-37	150	PVC	150	-0.48	0.03	0.007
353	P-38	150	PVC	150	4.09	0.23	0.387
354	P-39	150	PVC	150	4.05	0.23	0.38
355	P-40	150	PVC	150	4.89	0.28	0.541
356	P-41	150	PVC	150	2.96	0.17	0.213
358	P-43	150	PVC	150	21.38	1.21	8.286
359	P-44	150	PVC	150	10.77	0.61	2.328
360	P-45	150	PVC	150	1.06	0.06	0.031
362	P-46	150	PVC	150	2.2	0.12	0.123
363	P-47	150	PVC	150	0.66	0.04	0.013
366	P-49	150	PVC	150	-7.18	0.41	1.099
368	P-50	150	PVC	150	-14.09	0.8	3.828
370	P-52	150	PVC	150	15.88	0.9	4.774
372	P-53	150	PVC	150	1.76	0.1	0.082
375	P-55	50	PVC	150	1.64	0.83	14.958
376	P-56	50	PVC	150	1.59	0.81	14.116
378	P-57	50	PVC	150	2.03	1.03	22.335
379	P-58	50	PVC	150	1.76	0.9	17.121
381	P-59	80	PVC	130	2.01	0.4	2.894
385	P-62	400	DCI	130	44.24	0.35	0.35

386	P-63	400	DCI	130	29.34	0.23	0.163
387	P-64	200	DCI	130	-14.45	0.46	1.287
389	P-65	200	DCI	130	0.24	0.01	0
390	P-66	200	DCI	130	-0.39	0.01	0
391	P-67	200	DCI	130	-0.32	0.01	0.001
394	P-68	150	PVC	150	34.86	1.97	20.49
395	P-69	150	PVC	150	20.62	1.17	7.747
397	P-70	200	DCI	130	12.75	0.41	1.021
399	P-71	200	DCI	130	10.84	0.35	0.755
401	P-72	200	DCI	130	9.3	0.3	0.57
403	P-73	200	DCI	130	7.94	0.25	0.424
405	P-74	200	DCI	130	6.45	0.21	0.29
407	P-75	200	DCI	130	5.17	0.16	0.192
409	P-76	200	DCI	130	3.86	0.12	0.113
410	P-77	200	DCI	130	2.67	0.09	0.055
412	P-78	200	DCI	130	0.85	0.03	0.006
413	P-79	200	DCI	130	-0.36	0.01	0.002
415	P-80	200	DCI	130	0.54	0.02	0.002
416	P-81	200	DCI	130	-0.87	0.03	0.007
438	P-98	200	DCI	130	-0.6	0.02	0.003
441	P-100	80	PVC	150	0.47	0.09	0.152
442	P-101	80	PVC	150	1.23	0.25	0.901
443	P-102	80	PVC	150	1.72	0.34	1.664
445	P-103	80	PVC	150	3.83	0.76	7.333
447	P-104	80	PVC	150	4.34	0.86	9.246
448	P-105	80	PVC	150	5.78	1.15	15.714
449	P-106	80	PVC	150	-1.49	0.3	1.281
454	P-110	80	PVC	150	4.05	0.81	8.124
455	P-111	90	PVC	150	2.15	0.34	1.413
456	P-112	90	PVC	150	8.09	1.27	16.512
457	P-113	90	PVC	150	7.37	1.16	13.877

459	P-114	90	PVC	150	7.87	1.24	15.683
461	P-115	90	PVC	150	6.32	0.99	10.433
462	P-116	90	PVC	150	4.83	0.76	6.348
468	P-119	90	PVC	150	1.66	0.26	0.878
470	P-120	150	DCI	130	0.32	0.02	0.005
472	P-121	150	DCI	130	1.79	0.1	0.109
474	P-122	150	DCI	130	0.56	0.03	0.012
476	P-123	150	DCI	130	-1.76	0.1	0.103
477	P-124	150	DCI	130	-3.67	0.21	0.416
482	P-127	150	DCI	130	1.77	0.1	0.108
483	P-128	150	DCI	130	-0.17	0.01	0.001
485	P-129	50	PVC	150	-0.86	0.44	4.586
486	P-130	50	PVC	150	-1.82	0.93	18.228
491	P-133	75	PVC	150	0.57	0.13	0.295
492	P-134	75	PVC	150	-0.81	0.18	0.57
494	P-135	75	PVC	150	-0.67	0.15	0.396
495	P-136	75	PVC	150	-1.98	0.45	2.953
498	P-137	75	PVC	150	-0.08	0.02	0.007
499	P-138	75	PVC	150	0.27	0.06	0.071
501	P-139	80	PVC	150	1.93	0.38	2.069
502	P-140	80	PVC	150	2.2	0.44	2.631
503	P-141	50	PVC	150	-0.92	0.47	5.182
504	P-142	50	PVC	150	-1.62	0.83	14.696
505	P-143	50	PVC	150	-0.92	0.47	5.106
506	P-144	50	PVC	150	-1.5	0.76	12.694
508	P-145	100	PVC	150	5.64	0.72	5.055
509	P-146	100	PVC	150	4.72	0.6	3.636
510	P-147	50	PVC	150	-0.74	0.38	3.457
527	P-159	150	PVC	150	3.61	0.2	0.308

Appendix-VIII

Type of line	D (mm)	D (inch)	A (inch ²)	Coefficient	\sqrt{p} (1/ inch ²)	Q (gal/min)	Q (gal)	Q (m ³ /year)
Transmission main	100	3.94	12.17	30.39	7.40	2,735.90	328,308.13	1,242.79
	110	4.33	14.72	30.39	7.40	3,310.44	397,252.84	1,503.78
	150	5.91	27.38	30.39	7.40	6,155.78	738,693.30	2,796.28
	200	7.87	48.67	30.39	7.40	10,943.60	1,313,232.53	4,971.16
	250	9.84	76.05	30.39	7.40	17,099.38	2,051,925.83	7,767.44
	300	11.81	109.51	30.39	7.40	24,623.11	2,954,773.20	11,185.12
	350	13.78	149.05	30.39	7.40	33,514.79	4,021,774.63	15,224.19
	400	15.75	194.68	30.39	7.40	43,774.42	5,252,930.13	19,884.66
	Sub total							64,575.43
Distribution main	50	1.97	3.04	30.39	7.40	683.98	82,077.03	1,367.95
	75	2.95	6.84	30.39	7.40	1,538.94	184,673.32	3,077.89
	80	3.15	7.79	30.39	7.40	1,750.98	210,117.21	3,501.95
	90	3.54	9.86	30.39	7.40	2,216.08	265,929.59	4,432.16
	100	3.94	12.17	30.39	7.40	2,735.90	328,308.13	5,471.80
	110	4.33	14.72	30.39	7.40	3,310.44	397,252.84	6,620.88
	150	5.91	27.38	30.39	7.40	6,155.78	738,693.30	12,311.55
	200	7.87	48.67	30.39	7.40	10,943.60	1,313,232.53	21,887.21
	300	11.81	109.51	30.39	7.40	24,623.11	2,954,773.20	49,246.22
		Sub total						
Total sum								172,493.05