ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Assessment of the Water Distribution Network of Adama City Water Supply System

---

A Thesis in Water Supply and Environmental Engineering Stream

By Dayessa Leta Merga

Advisor: Fiseha Behulu Muluneh (PhD)

December, 2019

Addis Ababa

A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil and Environmental Engineering (Water Supply and Environmental Engineering Stream)

APPROVAL

The undersigned have examined the thesis entitled '**Assessment of the Water Distribution Network of Adama City Water Supply System**' presented by **Dayessa Leta Merga**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

Fiseha Behulu Muluneh (PhD)		
Advisor	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date
Chair person	Signature	Date
Mebruk Mohammed (Dr. Ing.)		
Dean, School of Civil and Environmental Eng.	Signature	Date

DECLARATION

I confirm that research work titled "**Assessment of the Water Distribution Network of Adama City Water Supply System'**" is my own work. The work has not been presented elsewhere. Where material has been used from other sources it has been properly acknowledged.

Dayessa Leta Merga

ABSTRACT

Water distribution systems are designed to fulfill all requirements of potable water needed for decades. Initial system designs frequently consider any anticipated changes likely to happen. However, as time elapsed they slowly begin to fail to satisfy customers' requirements. Adama town is the capital city of Oromia regional state. It is also one of the largest city of the region as well as the country with a total population of around 547,987. The main objective of this study was to investigate the state of the existing water distribution system and evaluate the hydraulic performance of the water distribution network with the aid of computer analysis. The peak hour demand was analyzed to verify that the existing sizes of network pipes are sufficiently provide the minimum required pressure at all demand points. The minimum hour demand was analyzed for evaluation of pipe material and strength of the network.

To evaluate the existing performance of water distribution system, a model was developed utilizing Water CAD software. The model can be used to solve ongoing problems, analyze proposed operational changes, and prepare for unusual events. Calibration of data on pressure at different location were collected. The model run was performed for different scenarios to analyze the system model, what if conditions. These scenarios are at average day demand, peak hourly demand and Minimum day demand. Comparing representative samples of the distribution main's pressure field-test with the model-simulated values showed a reasonable and small difference to calibrate the model. The model analysis result showed the different problems of the system, these are oversized and undersized pipes, zero flow velocity and low pressures (negative 87m up to 9m H_2O) due to pipe size and topography of the area.

Key Words: Water Distribution System, Modeling, WaterCAD, Hydraulic Performance, Water Demand, Maximum Pressure, Minimum Pressure, Velocity, Source, Adama.

ACKNOWLEDGEMENT

First and foremost, I am deeply grateful to my advisor Dr. Fiseha Behulu; for his dedicated and critical comments and closer supervision of the whole work for otherwise the thesis would not have been possible and completed on time.

My appreciation also goes to Dr. Ing. Geremew Sahilu, who shaped my tracks in civil engineering field by allowing me to add more bridge courses in the field of specialization.

I am also indebted to and give special thanks to my family for their encouragement and motivation during my study.

I would like to thank the Adama City Water Supply Enterprise staffs, especially Yasin Oumer, the previous general manager for his valuable data for the research.

Finally, I would like to thanks to all my friends; for their constructive comments and motivations lasted throughout undertaking my thesis work and for their personal support during my M.Sc study.

Table of contents

APPROVAL ... ii
DECLARATION ... iii
ABSTRACT ... iv
ACKNOWLEDGEMENT ... v
ACRONYMS ... xii
1. INTRODUCTION ... 1
 1.1. Background ... 1
 1.2. Statement of the Problem ... 3
 1.3. Research Questions ... 4
 1.4. Research Objective ... 4
 1.5. Scope of the Study ... 5
 1.6. Structure of the thesis ... 5
2. LITRATURE REVIEW ... 6
 2.1. Urban Water Supply Demand ... 6
 2.2. Water Distribution System ... 6
 2.3. Types of Water Distribution Network ... 7
  2.3.1. Branching Systems ... 7
  2.3.2. Grid Systems ... 7
  2.3.3. Ring Systems ... 7
  2.3.4. Radial Systems ... 7
 2.4. Mode of Water Distribution system ... 8
  2.4.1. Gravity Distribution ... 8
  2.4.2. Pumping Without Storage ... 8
  2.4.3. Pumping with storage ... 8
 2.5. Components of Water Distribution Networks ... 8
  2.5.1. Hydraulics ... 8
  2.5.2. Negative Pressures ... 9
  2.5.3. Appropriate pressures ... 9
  2.5.4. Sources and Treatment Works of Water Distribution System ... 10
  2.6. Water Distribution Facilities ... 10

2.6.1. Service Reservoir 10
2.6.2. Type of Reservoirs 11
2.7. Computerized Hydraulic Modeling 12
2.7.1. Advantages of Computerized Network Analysis 12
2.7.2. Enhancing Computer Control System 13
2.7.3. Type of Hydraulic Modeling 14
2.7.3.1. EPANET 14
2.7.3.2. WaterCAD 14
2.7.3.3. Cybernet 15
2.7.3.4. H_2ONET 15
2.7.3.5. SynerGEE Water 16
2.8. Principles of Network Hydraulics 17
2.8.1. Conservation of Mass 18
2.8.2. Conservation of Energy 18
2.9. Water Distribution Simulation 21
2.9.1. Steady State Simulation 21
2.9.2. Extended Period Simulation 22
2.10. Hydraulic design parameters 22
2.10.1. Pressure 22
2.10.2. Flow rate 23
2.11. Model Calibration 23
3. MATERIAL AND METHODS 24
3.1. Description of the Study Area 24
3.1.1. Location 24
3.1.2. Topography 24
3.1.3. Climate 25
3.1.4. Population 25
3.2. Description of Existing Water Supply System 25
3.3. Components of Water Distribution systems 26
3.3.1. Transmission Main 26
3.3.2. Pressure in the Distribution Main 26
3.3.3. Velocities in the Mains 27

3.3.4. Locations of Reservoirs 28
Coverage of Water supply system 29
3.4. Source of Data 30
3.4.1. Pressure Measurement 31
3.4.2. Pressure sampling location 31
3.4.3. System Maps 32
3.4.4. Topographic Maps 33
3.4.5. Equipments Used 33
3.5. Hydraulic Model: Water CAD 33
3.5.1. Modeling Base Water Demand 34
3.5.2. Population Projection 34
3.5.3. Climatic and Socio- Economic Adjustment Factors 35
3.5.4. Network Simulation 41
3.5.5. Modeling Tools 42
3.5.6. Computational Procedures 42
3.6. Building Data Base for Modeling Water Supply Systems 42
3.6.1. Water Demand Data 43
3.6.2. Water Supply Sources data 43
3.6.3. Transmission and distribution network 43
3.6.4. Pumping Stations 43
3.6.5. Reservoirs 43
3.6.6. Synchronization of data base 44
3.6.7. Model calibration and validation 44
4. RESULTS AND DISCUSSIONS 46
4.1. Estimated water demand 46
4.1.1. Population forecasting 46
4.1.2. Domestic Water Demand 47
4.1.2.1. Per capital water consumption 47
4.1.2.2. Average water demand 47
4.2. Water distribution network analysis 49
4.2.1. Nodal Demand Calculation 49
4.2.2. Model Analysis 49

4.2.3. Steady-state Analysis 49
4.2.4. Extended-Period Simulation 49
4.3. Evaluation of Distribution System 51
4.4. Model calibration and validation 53
4.4.1. Model Validation 54
4.4.2. Water loss Analysis 55
4.4.3. Percentage of water loss 56
5. CONCLUSION AND RECOMMENDATION 57
5.1. Conclusion 57
5.2. Recommendation 58
References 59

LIST OF FIGURES

Figure 3. 1: Location and Topography Map of Adama Town 24

Figure 3. 2: layout and supply zones of distribution system. 28

Figure 3. 3: Graph of demand pattern..40

Table 4. 1: Projected Population of Adama Town, Wonji Town and the surrounding village for the year (2011-2030)...46

Figure 4. 1: Peak and Minimum Hours Consumption Pattern 51

Figure 4. 2: Parts of the Network Requiring Improvement 53

Figure 4. 3: Correlation of Observed and Simulated Pressure 55

Figure 4. 4: Maintenance of Pipe Burst Observed During Field Visit. 56

LIST OF TABLES

Table 2. 1: Model Comparisons 16

Table 2. 2: Model Advantages and Disadvantages 17

Table 3. 1: Location and Topography Map of Adama Town 24

Table 3. 2: Recommended Operating Pressure in the Distribution Network 27

Table 3. 4: Location of Reservoirs 29

Table3. 6: Population Growth Rate 34

Table 3. 7: Percapita Water Demand of the City (Liter Per Day) 35

Table 3. 8: Climate Adjustment Factors 36

Table3. 9: Socio-Economic Adjustment Factors Climate Adjustment Factors 36

Table3. 10: Recommended Water Demand Peak Factors 40

Table3. 11: Pipe Roughness for Different Pipe Material. 41

Table 4. 1: Projected Population of Adama Town, Wonji Town and the surrounding village for the year (2011-2030)..46

Table 4. 2: Summary of Domestic Water Demand 48

Table 4. 3: Average Day Demand for Each Zone 49

Table 4. 5: Locations of the Representative Samples of Supply Main Nodes and the Corresponding Home Faucet. 54

ACRONYMS

ACWSSE	Adama City Water Supply and Sewerage Enterprise
AAWSA	Addis Ababa Water and Sewerage Authority
CSA	Central Statistical Agency
C	Hazen-Williams coefficient
CWTM	Clear Water Transmission Main
CW	Clear Water
D	Diameter
DCI	Ductile cast iron
GI	Galvanized iron
mm	Millimeter
masl	meter above sea level
MWR	Ministry of Water Resource
OWRB	Oromia Water Resource Bureau
OWMEB	Oromia Water, Mineral and Energy Bureau
OWWDSE	Oromia Water Work Design and Supervision Enterprise
Q	Discharge
UAP	Universal Access Program
WHO	World Health Organization
UN	United Nations
UFW	Unaccounted for water
V	Velocity
Z	Elevation

1. INTRODUCTION

1.1. Background

Water is the most important natural resource in the world since without it life cannot exist and most industries could not operate. Although human life can exist for many days without food, the absence of water for only a few days has fatal consequences. The presence of a safe and reliable source of water is thus an essential prerequisite for the establishment of a stable community. Water, a valued resource, is used as the main raw material by our civilization. It is usually found in lakes, rivers, reservoirs and underground sources. From the sources it is abstracted and pumped or gravitated into supply network systems. Water supply systems are mandatory for supplying water to the users. The main components of water supply systems are: (1) Water source; (2) treatment works; (3) transmission and distribution network (i.e. trunk mains, distribution pipes and main reservoirs); and (4) electromechanical components.

The water distribution system is a hydraulic infrastructure consisting of various elements such as pipes, tanks, reservoirs, pumps, and valves. All of them are crucial in delivering water of acceptable quality with specified pressure. The distribution systems can be either looped or branched. In earlier times appearances of water distribution systems were not a complex network system. They were a system of single line or very few lines. In ancient cities aqueduct supplied water through tubular conduits from the source and branched out into the city and the palace (Walski, 2004). When cities were small, obtaining clean water was not a major problem; however, as cities grew to larger populations and much higher densities, there was a much greater need for water infrastructure. With advances in science, particularly in engineering, more complicated systems were emerged with new arena of pipe analysis.

Analysis of a pipe network is essential to understand or evaluate urban water distribution systems. These networks of pipes are either branched type or interconnected in looped system. In a branched pipe network, the pipe discharges are unique and can be obtained simply by applying discharge continuity equations at all the nodes. However, in case of a looped pipe network, the number of pipes are too many to find the pipe discharges by merely applying discharge continuity equations at nodes. The analysis of looped network is carried out by using additional equations found from the fact that while traversing along a loop, as one reaches at the starting node, the net head loss is zero (Swamee et al., 2008).

A water distribution network simulation model represents a real system using mathematical formulations to predict the system responses under a wide range of conditions without interrupting the actual systems (Walski et al., 2001). There are two types of simulations: (1) steady-state; and (2) extended period simulation. Steady-state refers to the conditions where the hydraulic properties remain constant with time. In extended period simulation (EPS), the hydraulic states of the system varies over time. It is necessary when simulation is performed to predict the response to a unique set of hydraulic conditions (for example, peak hour demand). Steady-state simulation determines the flows, pressure, valve position, pump operating attributes at a certain time. Whereas, EPS simulates the variation of tank water levels, pressure, flows in response to varying demand conditions (Cesario, 1995).

The simulation of hydraulic behavior of pipe network in which pressurized water is fed is not an easy task. It involves solving a set of simultaneous non-linear equations, for example; continuity equation (conservation of flow to be satisfied at each node), energy equation and the equation that relates pipe flow and head-losses, such as the Hazen-Williams, Darcy-Weisbach and Manning's equations. With the advent of soft computing technology, researchers have been interested to use this technology in problems with iterative computations. There are many useful and efficient computer programs available for water distribution network simulation. WaterCAD (Bentley) is one such popular simulation tool which plays an important role in the layout, design and operation of the network. The water engineers use this simulation model to determine the optimal (least-cost) pipe sizes for supplying water to the consumers or to determine the optimal network parameters (pipe roughness coefficients and nodal demands) to increase the reliability of the model. Traditional approach uses a trial and error method. They assume one trial pipe sizes or network parameters and check the adequacy of the model. If the assumed variables are not adequate to satisfy the hydraulic conditions, for example, the engineer makes further changes to the values of the variables to arrive at a workable alternative.

The currently serving water distribution pipe network system of Adama town is inaugurated in November 2002. However, the town population is growing rapidly with expansion of the town to pre-urban areas. Due to burden on the water distribution system now it is facing some problems associated with demand-supply misbalance. Hence, it is considered that analyses of pipe systems using models are a recent approach to evaluate the performance of water distribution network.

1.2. Statement of the Problem

Insufficiencies of water supply along with the worsening of water quality in a distribution system are the major problems facing city water works all over the world. The problem is especially severe in most developing-country cities and towns including Adama; where increased urbanization, population growth, poor city planning, and shortage of sufficient resources creating combined effect.

Frequent pipe bursts and excessive leakages in the network due to the existence of old pipe lines have also decreasing the coverage capacity of the service. Recent studies have shown that unaccounted for water has been increasing from 15.44% to 45.46% of water production (OWWDSE, 2011). Furthermore, there is no alternative water source for emergency case; if supply fails from Awash River; water supply situation is becoming worst in the town due to lack of emergency water supply (OWWDSE, 2011).

Commonly water scarcity has enhanced by adverse pressure within distribution system. High leakage and pipe failure (due to unmaintained maximum pressure) as well as provision of inadequate supply (due to unmaintained minimum pressure) are situations, which transmit water shortage within distribution system. Hence, studying the hydraulic parameters, the variations, and the relations between them and other factors, which control the performance of the water supply networks for increasing the efficiencies of the water supply distribution systems, is necessary to mitigate the problem. Therefore, this study aims to investigate the performance of water distribution network of Adama City Water Supply System using computer modeling.

1.3. Research Questions

- What is the performance of Adama City water distribution system?
- What are the major factors for intermittent water supply experienced in Adama City water distribution network?
- How much water is lost in the system comparing with system production?
- What are the primary sources contributing to water loss in the City water system?

1.4. Research Objective

General objective:

The objective of this study is to evaluate the performance of the full existing water distribution system using hydraulic simulation software (WaterCAD) and recommend changes, if any, in the existing system and to use the model to control the distribution system.

Specific objectives:

To fulfill the above general objective, the following specific objectives are used.

- To assess the hydraulic performance of Adama City water distribution system.
- To assess the major factor of water loses in the existing water distribution network.
- To predict the City feature water demand and give appropriate recommendation.

1.5. Scope of the Study

The objective of this research is to present the fundamental concept of hydraulics applied to Adama 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 performance of water distribution network of Adama City water supply system in Eastern Oromia region of Ethiopia and it mainly focus and was assess to identify the hydraulic performance and the factors for intermittent supply, water loss, and leakage management strategy of the town water distribution system. This was achieved with hydraulic modeling (Water CAD software), water loss analysis, and by made of discussion with the town water utility personnel to gather relevant information in the subject area. But, due to lack of enough budgets, chemical reagents, resources/ logistics and distance of the study area from laboratory these research exclude the water quality analysis in the distribution system of the study area.

1.6. Structure of the thesis

Chapter One: The introduction part contains about the background of the research, statement of problem, general objective, specific objectives, research questions, and the scope and limitations of the research.

Chapter Two: It contains different reviewed literatures which were related to the objective of this research work.

Chapter Three: It includes explanation about description of the study area and detail descriptions of the methodology work.

Chapter Four: It contains the results and discussion part of research outputs.

Chapter Five: Finally the conclusion and recommendation part of the research work is compiled under the fifth chapter.

2. LITRATURE REVIEW

2.1. Urban Water Supply Demand

Water demand is defined as the volume of water quested by users to satisfy their needs. In other way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Wallingford, 2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use. Urban water demand is classified in to different categories: the domestic water demand that includes in house use and out of house use is among the others. Urban water demand is usually quoted in terms of liter per capital per day (l/cap/day) (Mwendera et al, 2003). In many African towns, urban water demands are often non-homogeneous.

2.2. Water Distribution System

The distribution system can be categorized into gravity type and pump boosting type, depending on the height relation between the service reservoir and the distribution area. A water network system is created or expanded to supply a sufficient volume of water at adequate pressure from the supply source to consumers for domestic, irrigation, industrial, fire-fighting, and sanitary purposes. Pipe failure in water distribution systems disrupts the water supply to consumers and reduces the reliability of the system. It has been found that about 35% to 60% of the supplied volume is wasted due to pipe leakages (Babovic et al. 2002). Therefore, inspection, control and planned maintenance and rehabilitation programs are necessary to properly operate existing water distribution systems (Saegrov et al. 1999).

A well-intended water distribution network is very crucial in the development of urban areas. A well-intended water distribution network is very crucial in the development of urban areas. The goal of water distribution systems are to deliver drinking water for all areas satisfying design demands and pressure (Ayad et al.2013). In the design stage it is of concern to arrive at the least-cost solutions that satisfy a set of limits including demand and pressure requirements. Often it is also of interest to arrive at less expensive solutions that, however, interrupt slightly the constraints. Consequently, research interests have been concentrating on the development of efficient evolutionary algorithms (optimization techniques) to search for the optimal combination of decision variables (e.g. pipe diameters) from a large number of solutions (Alves et al2014).

2.3. Types of Water Distribution Network

According to (Tomas, et al., 2003), the water distribution networks can classified as explained below.

2.3.1. Branching Systems

This type of distribution networks is the most economical system, and common in the developing countries due to its low cost. In this system, when there is a need for developing the network, new branches follow that development and new dead end will be constructed. The branching systems have some disadvantages such as the following:

- The dead ends cause accumulation of sediments, which result in increasing contamination and health risks.
- The maintenance operation upstream of the network will prevent water to reach the downstream due to the interruption of the whole area of maintenance.
- The fluctuating demand causes high-pressure oscillations.

2.3.2. Grid Systems

There are no dead ends in this type of distribution networks. The maintenance operation did not affect the interruption on the whole area as in the branching system, this type of layout is highly desirable because, for any given area on the grid, water can be supplied from more than one direction. This results in substantially lower head losses than would otherwise occur and, with valves located properly, allows for minimum inconvenience when repairs or maintenance activities are required. The whole area is covered with mains that form the grid system.

2.3.3. Ring Systems

The mains form a ring around the area under service, secondary pipes connecting the mains and delivering the water to the consumers.

2.3.4. Radial Systems

The area under service in the radial system is divided into subareas, and a storage tank is placed in the center of each subarea to supply water to the consumer.

2.4. Mode of Water Distribution system

2.4.1. Gravity Distribution

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

2.4.2. Pumping Without Storage

In this method of distribution, water is pumped directly into the mains with no other outlet than the water actually consumed. The pumping rate should be sufficient to satisfy the demand. This method is the least desirable way of distribution; the power failure leads to complete interruption in water supply. An advantage of direct pumping is that a large fire service pump may be used which can run up the pressure to any desired amount permitted by the construction of mains.

2.4.3. Pumping with storage

In this method, an elevated tanks or reservoirs are used to maintain the excess water pumped during periods of low consumption, and these stored quantities of water may be used during the periods of high consumption. This method allows fairly uniform rates of pumping and hence is economical. [Steel, E.W. and T.J.McGhee, (1979)].

2.5. Components of Water Distribution Networks

2.5.1. Hydraulics

The purpose of a system of pipes is to supply water at adequate pressure and flow. However, pressure is lost by the action of friction at the pipe wall. The pressure loss is also dependent on the water demand, pipe length, gradient and diameter. Several established empirical equations describe the pressure–flow relationship (Webber, 1971), and these have been incorporated into network modeling software packages to facilitate their solution and use. When designing a piped system, the aim is to ensure that there is sufficient pressure at the point of supply to provide an adequate flow to the consumer. For example, in England and Wales, water companies are required to supply water to a single property at a minimum of 10 m head of pressure at the boundary stop tap with a flow rate of 9 l/min (OFWAT, 1999). This minimum pressure increases as the number of properties supplied through a single service pipe. [2004 World Health Organization. Safe Piped Water: Managing Microbial Water Quality in Piped Distribution Systems]

2.5.2. Negative Pressures

Situations that may give rise to negative pressures should always be avoided. Faecal organisms and cultivable human viruses may be present in groundwater adjacent to a pipeline and drawn into a pipe during transient low or negative pressures (Le Chevallier et al., 2003).

Hydraulic models can be used to identify where, when and how negative pressures may occur. Preventative measures such as system reinforcement may then be identified and implemented. Until such measures are effective, staff responsible for the daily operation of the network should be informed of these situations and hence where, when and how contamination of the network may occur. Such situations may occur where there are: -

- Properties on high ground.
- Remote properties at the end of long lengths of pipe.
- Demands that are greater than the design demand.
- Pipes of inadequate capacity (too small diameter).
- Rough pipes (e.g. corroding iron pipes or pipes with a build-up of sediment).
- Equipment failures (e.g. pumps and valves).

2.5.3. Appropriate pressures

Pressure at any point in the system should be maintained within a range whereby the maximum pressure avoids pipe bursts and the minimum ensures that water is supplied at adequate flow rates for all expected demands. This may require pressure boosting at strategic locations in the network (WHO.2004). In general, Water distribution systems can be divided into four main components:

- Water sources and intake works
- Treatment works and storage
- Transmission mains
- Distribution network.

2.5.4. Sources and Treatment Works of Water Distribution System

Untreated water (also called raw water) may come from groundwater sources or surface waters such as lakes, reservoirs, and rivers. The raw water is usually transported to a water treatment plant, where it is processed to produce treated water (also known as potable or finished water). The degree to which the raw water is processed to achieve portability depends on the characteristics of the raw water, relevant drinking water standards, treatment processes used, and the characteristics of the distribution system (Tsakiris, 2014). Before leaving the plant and entering the water distribution system, treated surface water usually enters a unit called a clear well.

The clear well serves three main purposes in water treatment. First, it provides contact time for disinfectants such as chlorine that are added near the end of the treatment process. Adequate contact time is required to achieve acceptable levels of disinfection (Japan Water Works Association, 1990). Second, the clear well provides storage that acts as a buffer between the treatment plant and the distribution system. Distribution systems naturally fluctuate between periods of high and low water usage, thus the clear well stores excess treated water during periods of low demand and delivers it during periods of peak demand. In the case of groundwater, many sources offer up consistently high quality water that could be consumed without disinfection.

2.6. Water Distribution Facilities

The distribution system can be classified into gravity type and pump boosting type, depending on the height relation between the service reservoir and the distribution area. If any proper high place is available in or near the distribution area, the service reservoir is located there to adopt gravity flow type, and if not available, pump-boosting type is adopted (Davis, 2010). The design distribution flow in the normal state is the maximum hourly distribution flow in the design daily supply of the design distribution area covered by each distribution pipeline, and is decided on the assumption that all the customers in the distribution are use water simultaneously at the time (Davis, 2010).

2.6.1. Service Reservoir

The two main functions of distribution reservoirs are to equalize supply and demand over periods of varying consumption and to supply water during equipment failure or for fire demand. The location of service reservoir should be at the center of the distribution area or as close to it as possible, and if any proper high place is available, pipe distribution can be realized. If there is no high place, pump boosting type distribution is adopted. It is usually economical to have equalizing reservoirs at various points in the distribution system so that main supply lines, pumping plants, and treatment plants can be sized for maximum daily instead of maximum hourly demand. During hours of maximum demand, water flows from these reservoirs to the consumers. When the demand drops off, the flow refills the reservoir.

A mass diagram can be used to determine the required capacity of the reservoir. Equalizing reservoirs are usually built at the opposite end of the system from the source of supply, so that during peak flows the maximum distance from the supply to the consumer is cut in half. It is necessary for an equalizing reservoir to have an elevation high enough to provide adequate pressure throughout the system served. For the correct hydraulic grade, it is necessary to build the reservoir above the area it serves. If the topography will not allow a surface reservoir, a standpipe or an elevated tank must be constructed (Jeffrey and Gilbert, 2012).

2.6.2. Type of Reservoirs

The two main types of reservoir are the ground level type (GLR) and elevated water tank type (EWT). Whenever the local topographical conditions permit, ground level reservoirs are preferable. Ground level reservoirs will be usually be of solid block masonry or reinforced concrete, cylindrical or rectangular but under special circumstances may be of glass reinforced plastic (GRP). Elevated tanks will be cylindrical or conical in reinforced concrete (MoWIE.2006).

Capacity

According to (Shammas and Wang, 2016), the capacity of a service reservoir must be decided base on the following conditions.

- The standard effective capacity shall be the 12-hour amount of the design maximum daily supply of the service area, and it shall be increased, considering the regional characteristics, the stability of water works facilities, etc.
- The amount of water to be added for firefighting shall conform to water for firefighting.

2.7. Computerized Hydraulic Modeling

Most small communities do not have very complex networks as compared to cities; however, they have poor data and records regarding their systems. In such cases, when one has to evaluate the hydraulics and the water quality of the distribution systems, it is advantageous to use computer models. Computer models making use of hydraulic simulation software are capable of mimicking the behavior of a real time system and have the capability of predicting the performance of the same system for future ‘what if’ scenarios (Haestad Methods, 2003). Some rural water districts that have the capability of maintaining and updating real time models, have used hydraulic simulation models in conjunction with geographic information systems, allowing them to perform criticality studies with greater precision (Zhang, 2009). This can be cost effective as it will provide decision support in operation and maintenance of their systems.

2.7.1. Advantages of Computerized Network Analysis

Feasibility

The most important advantage of computer modeling is that it makes network analysis feasible. Without computerized techniques, analysis is slow and impractical, except for very simple systems. Before computerized network analysis, over design was the common reaction to uncertainty caused by the inability to accurately predict flows and pressures in a system. By providing reliable information, network analysis enables the user to more efficiently analyze, design, and plan water systems (Thomas et al.2003).

Cost

The cost of computer hardware and software is relatively small compared to the amount of money that can be saved by designing a water system efficiently and accurately. Water facilities are expensive, and the cost savings achieved through proper sizing and installation can range from thousands of dollars to millions of dollars. Efficient operating strategies developed through use of network analysis can also be used to minimize energy costs, thus increasing cost savings (Thomas et al. 2003).

Socio-economic/Environmental Impacts

Several socio-economic and environmental considerations make network analysis a, standard utility tool. Increasing construction costs, combined with increasing population and consumption, make systematic analysis necessary to efficiently design, plan, and operate a system. Water-consumption-management plans can be used to save water and to redefine consumption patterns that lead to more efficient use of facilities (Thomas et al. 2003).

2.7.2. Enhancing Computer Control System

Many utilities would like to move towards computer-controlled or, at least, computer-assisted real-time operation. Many utilities routinely use computer programs for off-line studies of operation and of capacity expansion. The trend towards real-time control is motivated by some or all of the following factors, in combinations that vary among systems (Aydin et al. 2015 and Roma et al. 2015).

- Operation of the existing system is becoming increasingly more complex. New facilities are added and the existing ones are further interconnected. Sources of different qualities, reliabilities, and costs are introduced. Demands increase, and it is more difficult to meet them reliably. All of these changes require system- wide, rather than local, considerations in the preparation of operating plans.
- Retirement of experienced operators, who often are not replaced by people of similar capability or experience.
- Aging systems fail more frequently, leading to difficult operational decisions that must be made quickly under stress.
- High operating costs justify investments in attempts to optimize.
- Control and computer hardware are rapidly becoming cheaper, more available, and reliable.
- Computer control systems in treatment plants, power systems, and water systems are becoming more common, providing experience from which to learn.
- Managers, engineers, and operators are more comfortable and less threatened by computers.
- Mathematical models, optimization algorithms, and control software have developed considerably in recent years.

2.7.3. Type of Hydraulic Modeling

Widespread introduction of personal computers has enhanced hydraulic design of distribution networks. Commercial programmes available on the market, sometimes even free of charge, enable a very precise and quick calculation, which makes them equally suitable for the design of simple rural systems or large urban networks of a few thousand pipes. Accessibility of such software and PCs to the engineers of developing countries has been significantly improved since the mid-nineties. There are different types of hydraulic models available for water supply distribution analysis and evaluation (Thomas 2003). They are as follows:

2.7.3.1. EPANET

EPANET, the least expensive of the models presented in this research, is a free software package developed by the U.S. Environmental Protection Agency (EPA), originally and primarily for use as an evaluation tool by any party concerned with distribution system water quality.

EPANET operates in a Windows environment for model output viewing and manipulation. Although EPANET performs extended period simulations only, the program comes equipped to model such water quality phenomena as reactions within the bulk flow and reactions within the pipe wall. The program's solution algorithms are extremely fast, and the low-flow convergence problems inherent in node-oriented systems have been at least partially resolved with the hybrid method. The major drawback of EPANET as compared to commercial modeling programs is the use of the text editor for data input. Although EPANET lacks graphical input capabilities, the program provides attractive, color-coded output mapping. Despite its limitations, EPANET, as an overall modeling package for predicting head losses, pressures, and water quality in a distribution system, performs quite well.

2.7.3.2. WaterCAD

WaterCAD, produced and marketed by Haestad Methods of Waterbury, Connecticut, is a stand-alone hydraulic modeling program containing its own graphical editor and strong modeling capabilities that features a Windows-based interface to EPANET. WaterCAD can produce a distribution system network either scaled or schematically and with or without underlying DXF background maps. The resulting network can be color-coded to reflect modeling results, and WaterCAD also carries adequate annotation capabilities.

Some of WaterCAD's modeling features include a scenario management tool, fire flow and water quality analysis capabilities, and graphing and profiling of model results and system appurtenance characteristics. WaterCAD also can generate contour plots to demonstrate areas of high pressure, low fire flow availability, hydraulic grade line elevation, and many other pertinent system attributes. WaterCAD provides both steady state and extended period simulation analyses.

For data input and output, WaterCAD uses tables that are contained directly within the modeling environment, as opposed to a text-editing program. Data for populating the model with can be written to and output can be written from these tables using the database connectivity feature of WaterCAD. WaterCAD also has the ability to connect with Environmental Systems Research Institute, Inc.'s (ESRI's), GIS programs using the SHAPEFILE for model data import and export.

2.7.3.3. Cybernet

Cybernet, also produced and marketed by Haestad Methods, contains the same hydraulic modeling capabilities as WaterCAD, but can operate within AutoCAD for Windows; Cybernet is basically WaterCAD with the ability to operate in the AutoCAD environment. This operating mode provides the user with all of the capabilities of AutoCAD release 14, thereby allowing for graphical compatibility with other drawings produced within an organization. The AutoCAD environment gives the software much more graphical flexibility in producing high-quality graphical output, along with the modeling results.

2.7.3.4. H_2ONET

H_2ONET is a modeling program provided by MW Soft, Inc., a software subsidiary of Montgomery-Watson out of Pasadena, California, which features a Windows-based AutoCAD interface to EPANET. Like Cybernet, H_2O NET uses the AutoCAD release 14 environment to create network model drawings with all the capabilities of AutoCAD; however, H_2ONET requires AutoCAD and cannot operate as a stand-alone program.

H_2ONET provides a large range of modeling capabilities, including scenario management, fire flow modeling and fire hydrant analysis, and water quality analysis. Some of the features that set H_2ONET apart include a supervisory control and data acquisition (SCADA) interface, which allows for the extraction of real-time modeling data directly from a SCADA system in an ASCII format for use in model calibration and operator emergency response training; and an energy management module for use in identifying the most energy-efficient and cost-effective operational policies.

2.7.3.5. SynerGEE Water

SynerGEE Water, the new water modeling software from Stoner Associates, out of Carlisle, Pennsylvania, does not use the hybrid method of equations for solving the network analysis. SynerGEE uses the Newton-Raphson method and nodal (or H) equations. Because SynerGEE products have the ability to effectively model large, complex systems in excess of 100,000 pipes, the program historically has been used mostly by clients with large distribution systems. However, the advanced modules in SynerGEE 3.0 make the program attractive to a utility system of any size. Table 2.1 compares each model using different criteria.

Table 2. 1: Model Comparisons

	EPANET	WaterCAD
Documentation Capabilities		
Diagnostic Messaging Capabilities	Yes	Yes
On-Line Help Service	Yes /No	Yes
Documentation Capabilities for Individual System Components.	No	Yes
Range of Applications		
Water Quality Analysis Capabilities	Yes	Yes
Fire Flow Analysis Capabilities	No	Yes
Ability to Establish Open Links with Database Software	No	Yes
Links to SCADA system	No	No
Links to Geographical Information Systems (GIS)	No	Yes
Graphical Display Capabilities		
Clear Annotation of Model Components	Yes /No	Yes
Site Layout Capabilities	Yes /No	Yes /No
Graphing/Profiling of System Components/Model Results	Yes	Yes
Contour Plots of Model Result Areas	Yes /No	Yes
Ease of Use		
Scenario Management Capabilities	No	Yes
Software User Support	No	Yes
Windows Environment	Yes	Yes
Notes :- Yes/ No - Yes, but with limited functionality		

In general, all of the programs discussed have comparable capabilities and features. For simple water distribution systems with only a few pressure zones, all of the programs produce similar results when presented with similar problems. Therefore, the model evaluation ultimately involves comparing the differences in the presentation of model results, both graphical and textual, and the additional capabilities or features that each package offers. Also, the hydraulic model selected should be easy to use. Table 2.2 outlines the major advantages and disadvantages of each model.

Table 2. 2: Model Advantages and Disadvantages

Modeling Software	**Advantages**	**Disadvantages**
EPANET	Free Software	○ Inadequate Software Support ○ No Scenario Management ○ Text Editor for Data Input ○ Y2K Compliance unknown
WaterCAD	○ Relatively low pricing for capabilities. ○ Scenario Management ○ "Flex Tables" for Data Input/Output/Manipulation ○ Good reputation in the industry for user support ○ Ease of Use ○ Links to GIS ○ Passed Y2K compliance	○ Map printing capabilities directly from program are not as strong as AutoCAD-based programs.

2.8. Principles of Network Hydraulics

In networks of interconnected hydraulic elements, every element is influenced by each of its neighbors; the entire system is interrelated in such a way that the condition of one element must be consistent with the condition of all other elements (Walski et al., 2003). According to (K. Swamee and Sharma, 2009; E. Larock and et al., 2000; EPA, 2005; Walski et al., 2003; W. Mays, 2000) interconnections of hydraulic elements are defined in concepts of conservation of mass and energy.

2.8.1. Conservation of Mass

'The principle of conservation of mass dictates that the fluid mass entering any pipe will be equal to the mass leaving the pipe (since fluid is typically neither created nor destroyed in hydraulic systems). In network modeling, all outflows are lumped at the nodes or junctions' (Walski et al., 2003).

Pipes

$$\sum_{pipes} Qi - U \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

Where, Qi = inflow to node in i-th pipe (L^3/T)

U = water used at node (L^3/T)

The term for accumulation of water at nodes is required to describe stored and withdrawn water from tanks, while extended period simulation is regarded (Walski et al., 2003).

$$\sum_{pipes} Qi - U - ds / dt = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

Where, dS/dt = changes in storage (L^3/T)

2.8.2. Conservation of Energy

The principle of conservation of energy dictates that the difference in energy between two points must be the same regardless of the path that is taken' (Walski et al., 2003).

$$P1 / \gamma + z_1 + V^2 1 / 2g + = P2 / \gamma + z_2 + V^2 2 / 2g + hl \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. 2.3$$

Where:

P = the pressure (Ib/ft^2 or N/m^2)

γ = the specific weight of the fluid (Ib/ft^3 or N/m^3)

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

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

g = gravitational acceleration (ft/s^2 or m/ s^2)

hl = the combined head loss (ft or m)

Therefore, in connected network the difference in energy at any two point is equal to the energy increases from pumps and energy losses in pipes (frictional head loss) as well as energy losses in bending and fittings (minor head loss) that occur in the path between them.

There are three forms of energy:

- Pressure head - p / γ
- Velocity head - $V^2 / 2g$
- Elevation head – z

Head Loss

The total water loss in a distribution pipe and pipe fittings between two points of consideration is called head loss. There two types of head losses.

Surface Resistance

Head loss on the account of surface resistance, friction loss depends on:

- Pipe length.
- Coefficient of surface resistance, friction factor.

Form Resistance

The form-resistance losses are due to bends, elbows, valves, enlargers, reducers, and so forth categorized as minor loss.

Head Loss Equations

Hazen-Williams equation and the Darcy-Weisbach equation are the most commonly methods used for determining head losses in pressure piping systems.

Hazen-Williams Equation

The most frequently equation used in the design and analysis of water distribution networks, it was developed by the experiment and used only for water within temperatures normally experienced in potable water systems.

$$h_L = \frac{6.79L}{D^{1.16}}\left(\frac{V}{C}\right)^{1.85}$$ ………….. ……………………………………2.4

Where:-

h_L = Head loss in meter of water column

V = Average Velocity (m/s)

C = Hazen-Williams roughness coefficient (-)

L = Length of considered pipe section (m)

D = Diameter of pipe (m)

Q = discharge (Flow) through pipe (m3/s)

Darcy – Weisbach (Colebrook-White) Equation

This equation is a theoretically based equation, and its common use in the analysis of pressure pipe systems. For any flow rate and any incompressible fluid. It can be applied to open channel flow (free-surface flow).

$$h_L = \lambda \frac{L}{D}\frac{V^2}{2g}$$ ……………………………………………………….2.5

Where

h_L = Head loss in meter of water column, mwc

l = Darcy-Weisbach Friction factor (-)

L = Length of considered pipe section (m)

D = Diameter of pipe (m)

V = Velocity of flow through pipe (m/s)

g = Acceleration due to gravitational force (m/s2)

Q = discharge (Flow rate) through pipe (m3/s)

Because of non-empirical origins, the Darcy-Weisbach equation is viewed by many engineers as the most accurate method for modeling friction losses. However, the Hazen Williams formula is widely used for manual design and analysis of a pipe line system for its less complexity than Darcy Weisbach.

In any case, the end result of any design is to select and quantify appropriate and economical pressure pipes and fittings that can deliver the required quantity of water and pressure to consumers provided that all other design criteria are met.

2.9. Water Distribution Simulation

Simulation refers to the process of imitating the behavior of one system through the functions another. In our case, the term simulation refers to the process of using a mathematical representation or real system, called a model. Simulation can be used to predict system responses to under a wide range of conditions without disrupting the actual system, and solutions can be evaluated before time, money, and materials are invested in a real-world project.

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

2.9.1. Steady State Simulation

It computes the state of the system (flows, pressures, pump operating attributes, valve position, and so on) assuming that hydraulic demands and boundary conditions do not change with respect to time.

A steady-state simulation provides information regarding the equilibrium flows, pressures, and other variables defining the state of the network for a unique set of hydraulic demands and boundary conditions. Steady-state models are generally used to analyze specific worst-case conditions such as peak demand times, fire protection usage, and system component failures in which the effects of time are not particularly significant.

2.9.2. Extended Period Simulation

Extended period simulation tracks a system over time, and it is a serious of linked steady state run. The need to run extended period simulation is because the system operations change over time.

- Demands vary over the course of the day.
- Pumps and wells go on and off.
- Valves open and close.
- Tanks fill and draw.

Simulation Duration: An extended-period simulation can be run for any length of time, depending on the purpose of the analysis. The most common simulation duration is typically a multiple of 24 hours, because the most recognizable pattern for demands and operations is a daily one.

Hydraulic Time Step: An important decision when running an extended-period simulation is the selection of the hydraulic time step. The time step is the length of time for one steady-state portion of an EPS, and it should be selected such that changes in system hydraulics from one increment to the next are gradual. A time step, too large may cause abrupt hydraulic changes to occur, making it difficult for the model to give good results. Using an EPS model we can simulate based on the peak, minimum and average day demands.

2.10. Hydraulic design parameters

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

2.10.1. Pressure

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

2.10.2. Flow rate

It is the quantity of water passes within a certain time through a certain section. Velocity is directly proportional to the flow rate. For a known pipe diameter and a known velocity, the flow rate through a section can be estimated. Low velocities affect the proper supply and will be undesirable for hygienic reasons (sediment formation may cause due to the longtime of retention).

2.11. Model Calibration

A hydraulic network model calibration is necessary to take into account the physical changes that may occur in the network. Calibration includes the determination of network parameters (pipe roughness coefficients and nodal demands). The parameters are often not exactly known and very much sensitive to the age of the pipe which necessitates periodical measurement for optimal management of water delivery systems. Therefore, the parameters are determined through model calibration. Since the manual calibration is very time consuming and tedious, an automatic calibration technique is used.

In the calibration process, the parameters are adjusted so that the simulated pressure, pipe flow and tank level mimic the measured field value. Several studies (Ormsbee, 1989; Lansey and Basnet, 1991; Ferreri et al., 1994; Lingireddy and Ormsbee, 1998; Vitkovsky et al., 2000; Lingireddy and Ormsbee, 2002) have been carried out to establish an automatic calibration scheme. The main aim is to develop a robust, efficient and reliable automatic procedure that maintains close resemblance between the model output and the field results.

3. MATERIAL AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Adama town is located about 100 km South-East of Addis Ababa. It is situated in the Great Rift Valley on relatively flat lowland between two mountain ridges. The Geographical location of the town ranges from 8^{0}27.5’N-8^{0}35.7’N and 39^{0}13.5’E-39^{0}19’E (see the location of Adama on Ethiopia Figures 3.1).The town is accessible by a good asphalt road (Express way) from Addis Ababa. It is also accessible by asphalt and better gravel roads from West, East, and North and South directions of the country because of its strategic setting at a junction of roads leading to those areas.

3.1.2. Topography

Topography of Adama town varies from ground elevations of 1,595masl to 1,740masl. The southern central part of the town constitutes the lowest areas with ground elevation ranging from 1595masl to 1630masl. Areas with higher altitudes are found from the central to the northern and on the southern verges of the town. The altitude of these areas varies from 1630masl to 1740masl (Figure 3.1).

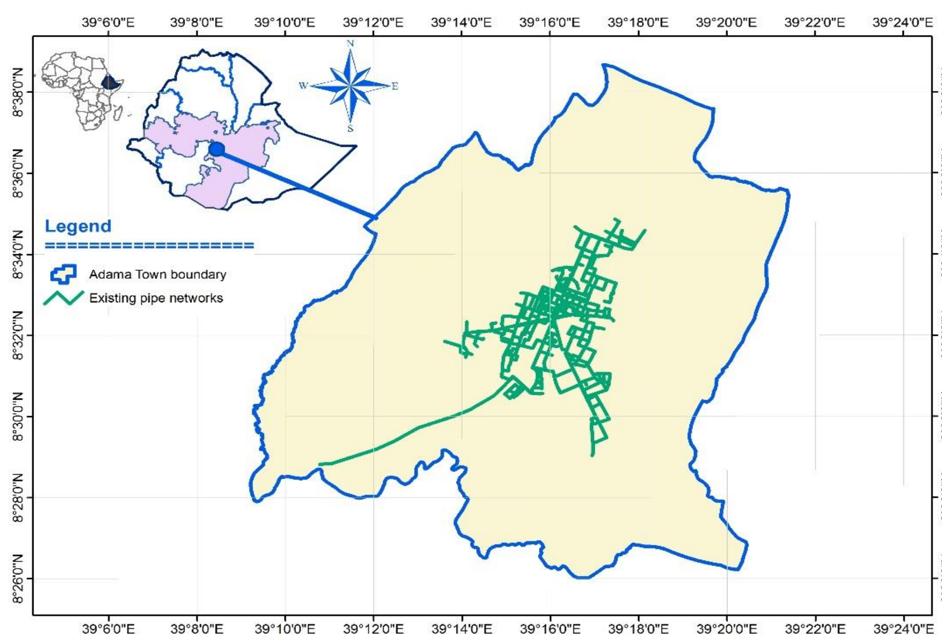


Figure 3. 1: Location (upper panel) and Topography Map (lower panel) of Adama Town

3.1.3. Climate

Adama town is located in the Grit Rift Valley of tropical climatic zone. There are four climatic seasons, Gena/Kremt, (rainy period) Bona/Bega, (dry period) Belg (small rains) and Meher (a spell between the long and small rains). The daily temperature varies between 5.5^{o}c during November/December and 35^{o}c during March to May. The mean annual ambient temperature is between 19 ^{o}c and 22 ^{0}c. Maximum temperatures usually occur in March to May. The mean monthly maximum exceeds 30 ^{0}c. Minimum temperatures are at their lowest in November. The mean annual rainfall for the years 1995-1998 is 822.5 mm. The wettest months are July and August. The average amount of rainfall in July is 230 mm and in August 200 mm.

3.1.4. Population

Data on existing and future population of the project has been estimated on the information obtained from CSA. In general, the population of the water supply project encompasses:

- Population residing in Adama town.
- Population residing in Wonji town and Wonju Sugar Factory.
- Floating Population.
- Rural villages found in and around Adama town and
- Those rural Villages are living along the transmission mains of the project.

For this study population data for Wonji town, Floating population, and rural village found in and around Adama town and rural village living along transmission main were collected from Adama town water supply feasibility study by Oromia Water Work Design and Supervision Enterprise. Additional data collected includes: reservoir data, source data, Pump data, and Valve data.

3.2. Description of Existing Water Supply System

Adama town water supply system was commissioned and inaugurated in November 2002. It has a modern water supply system which is managed by Enterprise and Board of administration. It was designed and implemented to cover the water demand of the town in two phases. As the 1st phase design of the system has almost been completed by the end of 2013; implementation of the second phase of the project should be required.

The Existing design capacity of the water supply system is **648l/s.** Currently the system is serving both Adama and Wonji towns with a population of more than **547,987,** which is by far more than its capacity. The existing Water Supply System Components are summarized in the following sections. (Adama Town Water Supply Feasibility study, OWWDSE 2011). At present the principal source of drinking water for the town of Adama is River Awash, located west of the town, about 11 km from the town.

3.3. Components of Water Distribution systems

3.3.1. Transmission Main

The transmission main, although it may have a small number of service connections on it, it is used to convey the majority of flow from the source, treatment plant, and/or storage facilities to the distribution system where the majority of service connections are located. It is designed to transport the maximum day demand of water to service reservoirs and for peak hour demand from reservoir to distribution network. It should also be designed for peak hour demands where direct pumping is required from source and/or treatment plant to distribution system.

3.3.2. Pressure in the Distribution Main

Gravity supply from the service reservoir at lowest water level condition. As a rule, a minimum manometeric head of 15m is considered as adequate during Peak Hour Demands. However, in exceptional cases, depending on the topography of the area, lower pressure levels may be permitted, but not less than 10 m. A maximum of 80m manometeric head, to avoid risking leaks and bursts in the distribution system, particularly during minimum flow conditions and when the static pressure would be dominant. Pipe pressure classes are chosen for the maximum pressure head that may occur under no or minimum consumption condition which is set at nil or 10 percent of the average day demand and the service reservoir at maximum water level. The operating pressures in the distribution network shall be as follows:

Table Figure 3. **2**: Recommended Operating Pressure in the Distribution Network

	Normal Conditions	**Exceptional Conditions**
Minimum	15 m water head	10 m water head
Maximum	60 m water head	water head

3.3.3. Velocities in the Mains

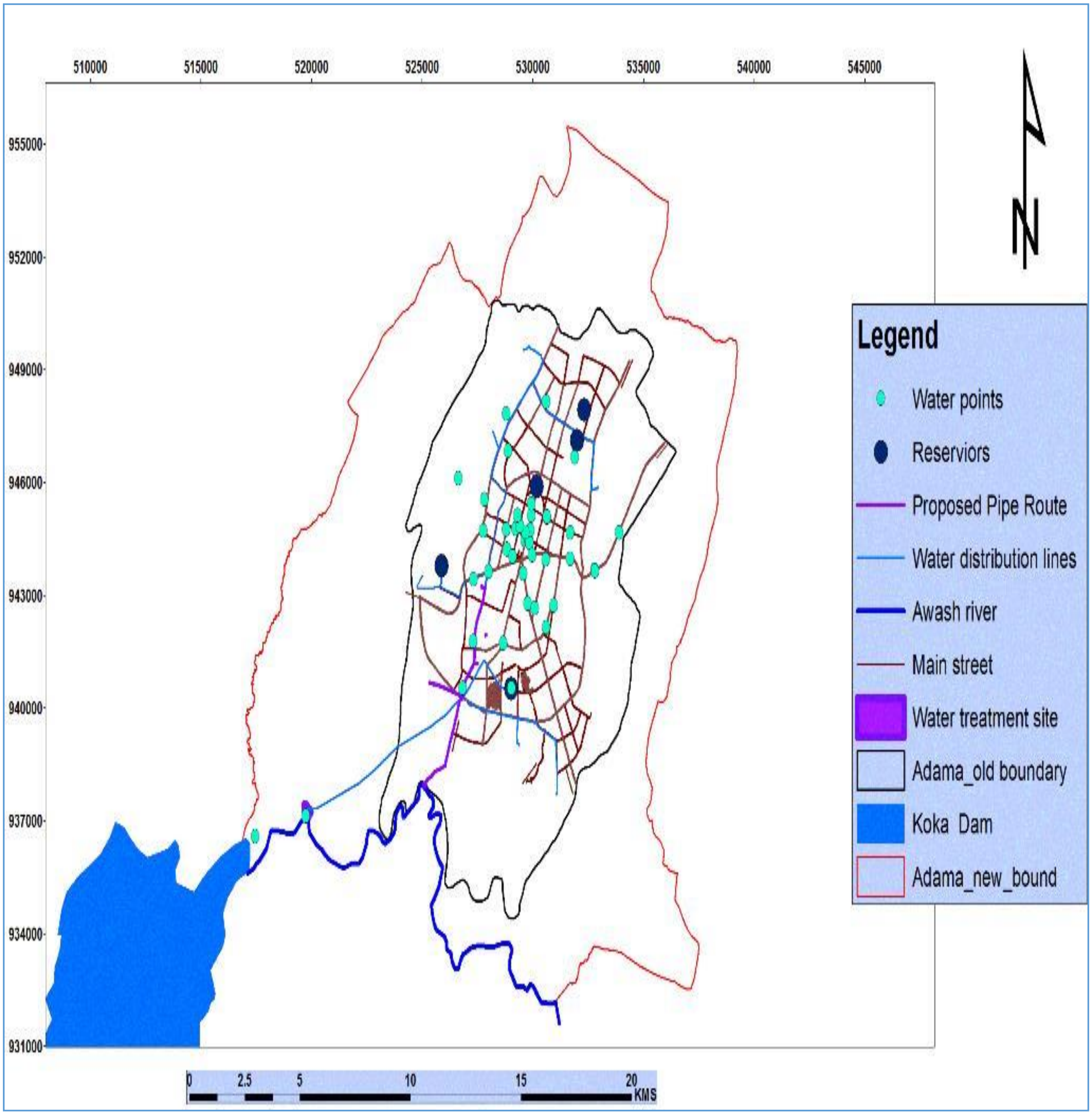
Water velocities shall be maintained at less than 2 m/sec, except in short sections. Velocities in small diameter pipes (<DN100) may need even lower limiting velocities.

- Maximum velocities of major transfer mains < 2.5 m/s.
- Maximum velocities of distribution mains < 2 m/s.
- Minimum 0.6 m/s.
- A minimum velocity of 0.6 m/sec can be taken, but for looped systems there will be pipelines with sections of zero velocity.

In general, the water distribution system includes the following significant system components.

- Service reservoirs, which are used for balancing the variable demands of the town.
- The distribution network, which distributes water to customers through its primary, secondary and tertiary components with a flow of gravity.
- Booster pumping Stations which are pumping water to the higher levels of the town where gravity flow could not have achieved by lower reservoirs.
- As mentioned earlier, the topography of Adama town varies from ground elevations of 1,595 to 1,740 masl. This topographic configuration of the town has necessitated dividing the distribution system into 5 (Five) separate pressure zones as listed below.

The water pumped from Awash River of Clear pump station enters into Lugo Reservoir, which is the main storage and supply zone of the town.



Source:-Adama town feasibility study report AutoCAD data.

Figure 3. 3: layout and supply zones of distribution system.

3.3.4. Locations of Reservoirs

It has been mentioned that the distribution system has been divided into 5 pressures zones. Each supply zone has been commanded and governed by the location and ground level of respective reservoir. In general, 7 (seven) existing and recently constructed reservoirs are found. Their respective locations have been summarized and presented in table below.

Table Figure 3. **4**: Location of Reservoirs

No	Name	Ground Level (Masl)	Size(m^3)	Location		
				Elevation	X(m)	Y(m)
1	Lugo Reservoir-1	1685	2000	1685.00	529,025.000	940,545.82
2	Lugo Reservoir-2	1685	4000	1,721.21	531,884.64	946,978.20
3	Adama University Reservoir	1720	1000	1,746.46	532,321.27	947,944.74
4	Dhaka Adi Reservoir	1745	1000	1,715.99	531,083.29	937,715.69
5	Boku Reservoir	1715	500	1,632.05	531,048.19	939,371.53
6	Gelma Aba Gada Reservoir	1750	200	1,659.00	530,205.21	945,920.17
7	Gelma Aba Gada Reservoir(2)	1757	4000	1,640.00	526,897.80	943,403.76
8	Kebele 02 Reservoir	1650	1000	1,757.00	525,885.00	943,783.00

Coverage of Water supply system

The existing and under construction distribution Systems covers around 50% or 2575 hectares of Adama Town. The network configuration is a combination of both branched and looped type. However, a looped system is dominating due to the convenient plan of the town. The general layout of the system has been presented in Figure 3.2

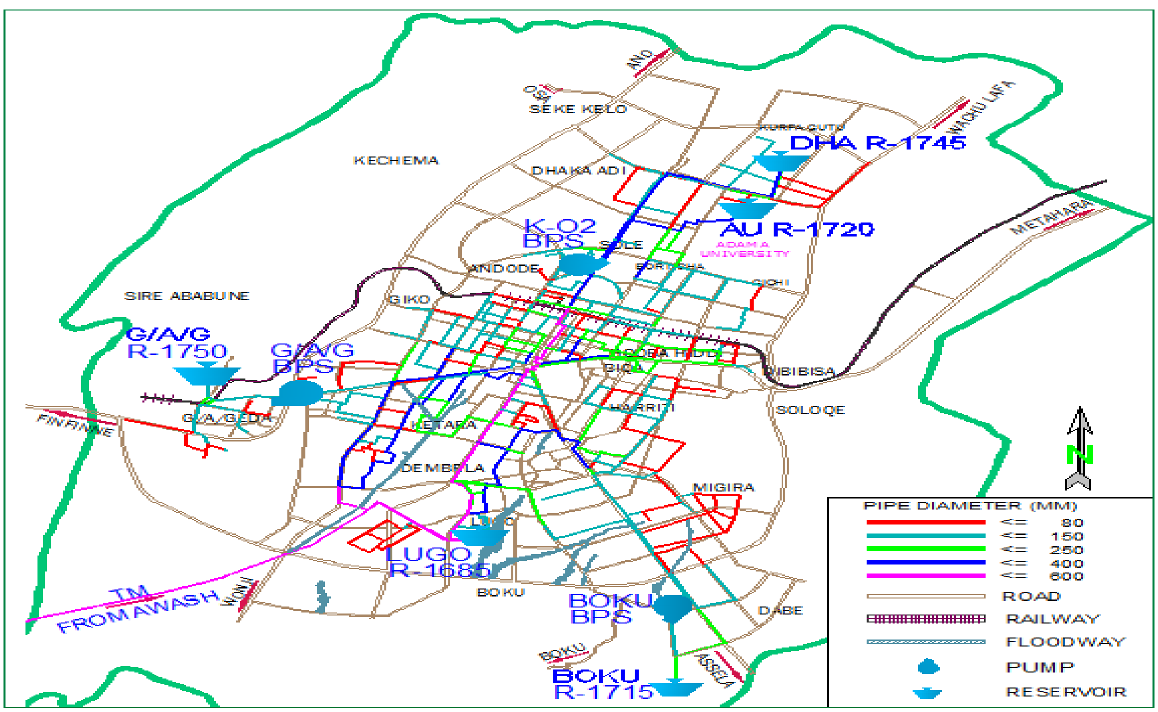


Figure 3. 5: Layout and distribution system

The total length of existing network is around 153.70 km. The total estimated quantities of existing and pipes new constructed are summarized in table below.

Table Figure 3. 6: Quantities of existing pipe network

ITEM NO	DIAMETER, DN (mm)	LENGTH (m)
1	40	870
2	50	11,020
3	65	1,440
4	80	23,770
5	100	22,530
6	150	30,670
7	200	23,480
8	250	390.
9	300	17,940
10	400	3,300
11	500	3,880
12	600	14,410
Total		153,700

As described in table 3.4, 30,670m of the system contains pipe of 150mm. This figure is relatively high when compared to 23,770, 23,480 of 80mm and 200mm pipe diameter respectively. A single pipe of 250mm diameter is the lowest. It is only 390m.

3.4. Source of Data

The source of data was involved both primary and secondary data. For the study, the primary data were obtained from pressure reading, elevation surveying and by made of discussion with water utility staff members to obtain additional relevant information on the subject matter. While, secondary data were collected from different literature reviews, design report, the town water supply service office existing documents such as system maps and topographic maps.

3.4.1. 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 Water CAD/GEMs (2008). "Water Distribution Design and Modeling, Full Version V8i".].

If the measurements are taken at a location other than, a direct connection to a water main (for example, at a house hose connection), the head loss between the supply main and the site where pressure is measured must be considered. Models can be calibrated using one steady-state simulation, but the more steady-state simulations for which calibration is achieved, the more closely the model will represent the behavior of the real system.

Acceptable levels of calibration

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

3.4.2. Pressure sampling location

A typical network representation of a water network may include hundreds or thousands of links and nodes. Ideally, during the water distribution model calibration process is adjusted for each link and each node. However, only a small percentage of representative sample measurements can be made available for the use of model calibration due to the limited financial and labor requirements for data collection. Therefore, it is of utmost importance to have a comprehensive methodology and efficient tool that can assist the engineer in achieving a highly accurate model under practical conditions [Bentley Water CAD/GEMs (2008). "Water Distribution Design and Modeling, Full Version V8i".].

Selection of sampling sites is typically a compromise between selecting sites that provide the greatest amount of information and sites that are most amenable to sampling. Sites should be spread throughout the study area and should reflect a variety of situations of interest, such as transmission mains and local lines, areas served directly from a source, and areas under the influence of tanks. In addition, sampling taps should be placed close to mains.

Data collection can be classified as either point reading (grab samples) or continuous monitoring. Point reading involves collecting data for a single location at a specific point in time, and continuous monitoring involves collecting data at a single location over time. For point readings, samples should be collected at locations where the parameter being measured is steady so that the sample measurement is representative of the location over a long period.

Ten representative sample measurements to the water main spread throughout the study area have been selected for the calibration. It was difficult to take measurement at a direct connection to the water main nodes, due to size of pressure gauge available for this research (. The measurements were taken at a location other than the direct connection to the water mains, nearer to the supply main nodes at homes faucet. The locations of the representative samples of a supply main nodes and the corresponding home faucet (field test).

3.4.3. System Maps

System maps are typically the most useful documents for gaining an overall understanding of a water distribution system because they illustrate a wide variety of valuable system characteristics. System maps may include information such as: -

- Pipe alignment, connectivity, material, diameter, and so on.
- The locations of other system components, such as tanks and valves.
- Pressure zone boundaries.
- Elevations.
- Miscellaneous notes or references for tank characteristics.
- ·Background information, such as the locations of roadways, streams, planning zones, and so on.

For this study system maps were collected from Oromia Water, Mineral and Energy Bureau and Oromia Water Work Design and Supervision Enterprise.

3.4.4. Topographic Maps

A topographic map uses sets of lines called contours to indicate elevations of the ground surface. Contour lines represent a contiguous set of points that are at the same elevation and can be thought of as the outline of a horizontal "slice" of the ground surface. For this study topographic maps of Adama Town were used to extract the elevation of nodes.

3.4.5. Equipments Used

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

3.5. Hydraulic Model: Water CAD

Water CAD is a state-of-the-art software tool and, primarily uses in the modeling and analysis of hydraulic and water quality modeling application of water distribution systems. But, the methodology is applicable to any fluid system with different characteristics, such as: steady or gradually-varying turbulent flow (Water CAD: USER MANUAL). The hydraulic simulation software used for this study is WaterCAD distribution Systems. Water CAD was selected due to ease of model building and operation and its greater programming capabilities as compared to EPANET. According to (Dawe, 2000), Water CAD is a powerful, easy-to-use due to the following reasons.

- Ability to Establish Open Links with Database Software.
- Links to Geographical Information Systems (GIS).
- Scenario Management Capabilities.
- Used for firefighting flow and constituent concentration analyses, energy consumption and capital cost management.
- Software User Support.
- Perform steady state and extended period simulations.
- Analyze multiple time-variable demands at any junction node.
- Quickly identify operating inefficiencies in the system.
- Perform hydraulically equivalent network skeletonization including data scrubbing, branch trimming, and series and parallel pipe removal.
- Efficiently manage large data sets and different "what if" situations with database query and edit tools.

Additional software

ArcGIS, was used to display the overlapped shape file of the distribution network on the topographic map of the town. While, Microsoft Excel sheet were used to organize elevation data, to calculate a repeated work of nodal base water demand requirement of distribution network simulation and for manual pressure validation work.

3.5.1. Modeling Base Water Demand

The following procedures were followed to estimate the current water demand of each node in the distribution network.

3.5.2. Population Projection

It is essential that the water supply system is designed to meet the requirements of population expected to be living in the town at the end of the design period taking into account of design period and annual growth rate. Estimates for the future population of the project are based on Growth Rate -Based on 2007 CSA Analytical Report. Population projections have been made using medium variant growth rates as shown below in table and equations respectively.

FIGURE 3.7: Population Growth Rate

Year(GC)	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030
Growth rate (%)	4.55	4.33	4.15	3.93	3.68

(Source: Oromia water, mineral and energy bureau)

Geometric increase method of population forecasting has been adopted for this research. Because this, method is mostly applicable for growing towns and cities having vast scope of expansion, like Adama town.

$$P_n = P_o(1 + 0.01r)^n \qquad \text{……………………………………..3.1}$$

Where

P_n = Design population (after n years)

P_p = Present population (at the start of design period)

r = Annual population growth rate in %

n = Design period in years.

Per capita Water Demand

The amount of water used per person per day for daily life and activity is known as Per capita water demand which uses as a base for estimating the domestic water demand of customers. It is normally a function of the daily basic needs but should be adjusted by socioeconomic development and climatologic factors. Hence, the per capital water consumption of the town was calculated using the annual water consumption recorded data and projected total population figure from 2015 to 2025 using the equation below.

Per capital consumption (L/C ⁄ d)

= Annual consumption ($m^3 * 1000\ l/\ m^3$)/ *Total population $*$ 365 ……..3.2

Taking into account the socioeconomic study of the town and experience of similar projects the Per capita water demand of the town is presented in tab Table below.

Table Figure 3. **8**: Percapita Water Demand of the City (Liter Per Day)

	Year					
	2015			**2025**		
Purpose of water	**HC**	**YC**	**PF**	**HC**	**YC**	**PF**
Drinking	1.5	1.5	1.5	1.5	1.5	1.5
Cooking	5.5	4	3.5	5.5	4	4
Ablution	10	8.5	6	12	9	7.5
Washing Utensils	5	5	2	6	5	2.5
Laundry	15	8	7	13	10	7
House Cleaning	4	3	0	5	5	2.5
Bath or shower	15	10	0	20	12	
Toilet	4		0	12	3.5	0
Total	60	40	20	75	50	25

3.5.3. Climatic and Socio- Economic Adjustment Factors

As mentioned in the aforementioned section the water used by a person normally depends on the climatic and socioeconomic conditions of the area. This means water is more used at hot areas than cold ones. In addition, reach people consume more water than the poor ones. These are adjusted by multiplying the adjustment factors with total domestic demand. Climatic and Socio- economic Condition Adjustment Factors are presented in the following two tables respectively.

Table Figure 3. **9**: Climate Adjustment Factors (Adama Town Water Supply Project Feasibility Study, Owwdse 2011)

Group	Mean Annual Precipitation (mm)	Factor
A	600 or less	1.1
B	601-900	1.05
C	901 or more	1

The mean annual precipitation of Adama Town is around **822.5mm**. This situation could categorize the project area under **Group B** with climatic adjustment factor of **1.05.** Socio-economically, the town can be grouped under "Towns having a very high potential for development, but lower living standards at present" with Socio-economic Adjustment Factor of **1.05**.

Figure 3.10: Socio-Economic Adjustment Factors Climate Adjustment Factors (Adama Town Water Supply Project Feasibility Study, Owwdse 2011)

Group	Description	Factor
A	Towns enjoying high living standards and with high potential for development	1.1
B	Towns having a very high potential for development, but lower living standards at present	1.05
C	Towns under normal Ethiopian conditions	1
D	Advanced rural towns	0.9

Non Domestic Water Demands

- The Non Domestic Water Demands normally include the following categories
- Industrial Water Demand,

- Commercial and Public Water Demands
- Livestock Water Demand,
- Unaccounted for Water (UFW)
- Water Demand for Fire Fighting

Industrial Water Demand

The development plans of many towns indicate that there are plans to establish some small to medium scale industries. In most cases big industries are assumed to have their own water supply systems. The following values can be used in the absence of defined water demands for specified industries:

- 5m3 /ha/day for small industries
- 10m3 /ha/day for large industries

Where there is no distinct data for the project area, it is recommended to take 5 to 10% of the domestic water demand, depending on the size of the project. About 10% has been taken for this thesis (OWWDSE, 2011).

Commercial and Public Water Demands

Commercial demand includes water requirement for restaurants, Cinema houses, railways, bus stations, shopping centers, Local drinks etc. whereas public demand includes water required by schools, hospitals, public offices, military camps, public parks, dispensaries, day-care centers and so on.

In case where exhaustive estimation of the public and commercial institutions is not possible it is recommended to take 20 to 40% of the domestic water demand, depending on the size of population. In this paper an average 30% has been assumed reasonable due to Small-scale industrial enterprises will not be categorized separately but should be included in the allowance for institutional and commercial demand. However, water demand for larger industries will be treated separately (MoWIE, 2006).

Unaccounted for Water (UFW)

Unaccounted-for water (UFW) is expressed as a percentage of the total water produced for the system. UFW arises from system leakage, water taken by illegal connections, inaccuracies in metering, overflowing of reservoirs, and legitimate unmetered use such as firefighting, flushing, etc. For this research unaccounted for water is obtained from Adama Town water supply and sanitation the UFW based on the amount of production versus the amount of bill collected.

Water Demand for Fire Fighting

Water demand for firefighting purposes shall be assessed on a town-by-town basis, depending on the existence of equipment and the capacity of any firefighting service. Fire hydrants shall be installed at public and municipality interest such as schools, shops, hospitals, fuel stations and at salient points of distribution network. This demand is taken off by increasing the volume of the storage tanks by 10 %. (Design criteria of urban water supply by Ministry of water resource, 2006).

Design Demands

The consumption patterns of different users of water supply services vary on hourly, daily and annual basis. Keeping records of these variations can help in developing standard peak factors for a given locality, which is the basis for the design of different water supply components. Poor estimation of these factors can lead to under or over design of water supply systems. To evaluate the different elements of a water supply scheme, the following design demands will be considered.

Average day demand:

The average daily demand is the total annual (average) water demand distributed over 365 days. It obtained by simply summing up the domestic and non-domestic demands as well as unaccounted for water (UFW). These form the basis to estimate the maximum day and the peak hour demand. For an average day demand, 20 to 24 hrs of pumping are recommended. The most common means of forecasting future water demand is estimating current per-capital water consumption, and multiply this by the projected population figure following the formula given below.

Qavg=per capital water consumption*Total population of the town……………….3.3

Maximum day demand/seasonal peak factor

The maximum day water demand is considered to meet water consumption changes with seasons and days of the week. It also represents the changes in demand with season and some special events happening in any specified year. The maximum day demand is obtained by multiplying the average day demand with the maximum day factor. In other words, the maximum day demands can be obtain by multiplying the average-day demands to the peaking factor applied to the node' (Venkateswara, 2005).

$Q_{max} = PF * Q_{avg}$……………………………………………………………………3.4

Where,

Q_{max} = Maximum day demand (cfs, m^3/s)
PF = Peaking factor between maximum day and average day demand
Q_{avg} = Average day demand (cfs, m^3/s)

Peak hour demand:

This occurs when particularly all the water taps are opened at a particular rush hour. Such event happens during morning hours when most people use water for bathing, cooking and could also occur towards the end of the day due to peoples' need for water for the same purpose after working hours. The peak hour demand is the highest demand of any one-hour over the maximum day. It represents the diurnal variations in water demand resulting from the behavioral patterns of the local population. The peak hour demand is obtained by multiplying the maximum day demand with the peak hour factor.

Demand diurnal pattern and multipliers factors

As stated earlier, both the maximum day and peak hour factors greatly depend on the size of the population to be served. It is always advisable to adopt peak factors developed from locally recorded consumption data or from a water services having similar climatic, cultural and socio-economic characteristics. In the absence of such data, the designer can flexibly adopt the peak factors given in the following table considering the local situation**.** Due to lack of historical recorded data for the study area, standard values are used in this study.

FIGURE 3.11: Recommended Water Demand Peak Factors

Population size	Maximum day factor	Peak hour factor
<2,000		2.6
2,000-10,000		2.4-2.2
10,000-50,000	1.3-1.5	2.2-1.8
50,000-80,000		1.8-1.7
>80,000	1.2	<1.7

Source: The World Bank Issue paper for project Design, Draft Final Report year

Demand Patterns

Water demand in a distribution system fluctuates over time. For example, residential water use on a typical weekday is higher than average in the morning before people go to work, and is usually highest in the evening when residents are preparing dinner, washing clothes, etc. This variation in demand over time can be modeled using demand patterns.

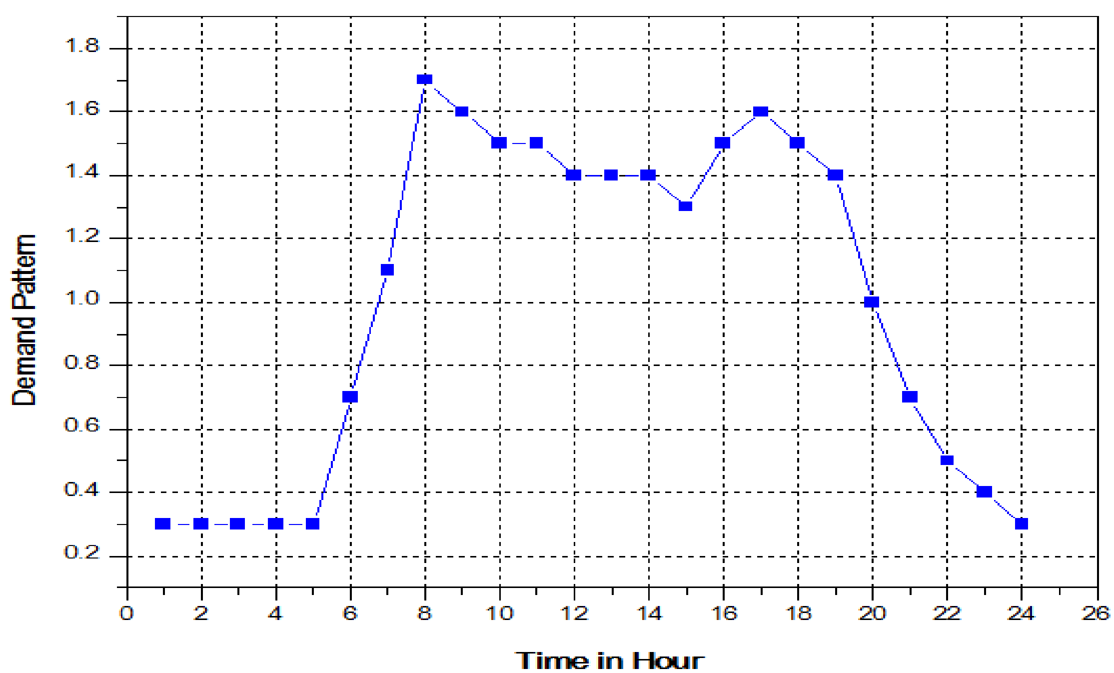


Figure 3. 12: Graph of demand pattern (owwdse,2011).

Demand patterns are multipliers that vary with time and are applied to a given base demand, most typically the average daily demand. The highest multiplier of demand pattern is equivalent to the peak hour demand factor. Hence distribution networks are designed for a capacity of peak hour demands (PHD).

Roughness coefficients for pipeline

The Hazen-Williams equation was developed for the action of friction at the pipe wall, because its formula uses a pipe carrying capacity factor. Higher C-factors represent smoother pipes (with higher carrying capacities) and lower C-factors describe rougher pipes (Tomas, et al., 2003). The value of roughness coefficient, C-factor is depending on pipe materials and its age (Tomas, et al., 2003).

Typical pipe roughness values are shown below. These values may vary depending on the manufacturer, workmanship, age, and many other factors. In designing the distribution network, we use the Hazen William formula with C value of UPVC, Steel DCI/GI as follow by taking the average of each material. For UPVC take 105, Steel 100 and DCI/GI take 105. Because we have no the exact year in which each pipe is installed.

Figure 3.13: Pipe Roughness for Different Pipe Material.
Source: Ministry of Water Resource Urban Water Supply Design Criteria.2006.

C-Value for Hazen-Williams			
Types of Pipes	**UPVC**	**Steel**	**DCI /GI**
New	130	110	120
Existing	100-110	90-110	100-110

3.5.4. Network Simulation

To build and simulate the hydraulic model, water CAD stand-alone, graphical editor water distribution modeling software was used. The water distribution network map was obtained from the town water service office, which was prepared as blue print drawn map report of distribution network and it was drawn in water CAD drawing pane with physical observation.

The network simulation was taken extended periods by consideration of hourly demand variation pattern over 24 hour flow duration analysis work. For this study, the network operational set-up was done by system international; SI unit and the project liquid were taken water at 20°c. The other model input were taken and carried out as mentioned below;

- Coordinate ………………….. X-Y
- Setting……………………….. Pressure
- Tank level……………………. Elevation
- Drawing Scale………………... Scaled
- Annotation Multiplier………... Adjusted for report visibility

3.5.5. Modeling Tools

To analyze and improve the existing water distribution system, a model was developed utilizing Water CAD software (Water CAD for Auto CAD 2004 software).

3.5.6. Computational Procedures

The physical characteristics of the system were represented in the model by nodes and pipes (or 'elements'). The nodes, joined together by pipes, represent: pipe junctions, changes in pipe diameter and the locations of system attributes such as valves and of large demands. The node and pipe data sets contain geographic co-ordinates, ground levels, basic demand information, internal diameter and friction coefficients, pump curves, service reservoir type and valve. Water demand was allocated to the node nearest to its draw off point. Nodal demands were distributed based on population estimates served by the nodes; with considerations of leakage and pattern of use.

3.6. Building Data Base for Modeling Water Supply Systems

The purpose of creating data base for a water supply system is to export and import data elements between the WaterCAD model and date base files so as efficiently perform the analysis of the system and produce the required out puts.

There are four ways to input the data required to build network which mainly depends on the format in which the data being stored, the complexity of the project and personal experience of designers. In case of this project Microsoft Excel Spread Sheets are used for establishing the data bases of the network as a starting point and other methods will be employed as required. The arrangement of basic project data and corresponding modeling elements have been outlined as follows.

3.6.1. Water Demand Data

The water demand data and respective supply points are represented as nodes junction nodes in WaterCAD as mentioned earlier. The water demands data and their respective points of locations have been spatially distributed in accordance with the master plan of the town and density of population or other water user customers. Either the average or maximum day demand of those areas could be used when modeling demand points.

3.6.2. Water Supply Sources data

All selected alternative water supply sources such as Boreholes, Dam and Storage, River Intakes and springs, and their respective locations, and sources quantities are modeled as reservoirs and arranged in Microsoft Excel Spread Sheets.

3.6.3. Transmission and distribution network

Knowing the locations of possible water supply sources and locations of Demand points, the next question is how to convey the required water from supply sources to demand points. Depending on the topographic conditions, the logical starts at this stage are the selection of best routes, laying out of transmission and distribution mains and definition of data elements required to build the network. The transmission mains are designed for a capacity of maximum daily water demands while distribution networks are for peak hourly demands of the project.

3.6.4. Pumping Stations

Pumping stations are designed for maximum daily water demands. Arrangement of appropriate locations for pumping stations, installation of wet wells and pumps are the modeling components of pumping stations.

3.6.5. Reservoirs

Service reservoirs (Tanks) are designed to balance the hourly fluctuations of water demands. Capacities are determined by either the storage requirements of one third maximum day demand or mass curve analysis of the inflow verses outflow systems. Service reservoirs are located at higher ground elevations where water will be distributed to target communities with flow of gravity.

Valves

Installation of Valves such as Pressure reducing valves (PRV) Air releasing Valves (ARV), Flow Control Valves (FCV), Flush out Valves (FOV), etc, at the required locations and data elements.

3.6.6. Synchronization of data base

Following the establishment of data base for the water supply distribution network, New Project File will be created for the design software. Then connection of data base with the project file will be performed to start the hydraulic analysis of the water supply system. The process of describing and interpreting data base of Microsoft Excel to WaterCAD data files is called data base connection. Finally, the synchronization process is conducted for matching the data bases of both Software's to commence the hydraulic analysis of the project.

In general, the approaches adopted for each of the system components to perform the computation for the present study was described below.

- All the existing water distribution system and other related available data have been collected.
- Missed data for modeling of the system have been generated using different software like Global mapper for the data of location and elevation of junction.
- The existing water distribution layout has been built using Water CAD for Auto CAD 2004 software tools, model representation.
- All the existing and generated data have been entered into the built model.
- The model has been simulated for single period and extended period.

3.6.7. Model calibration and validation

The computed parameters of a model and actual field observation are not always has the same value. Therefore, before discussion about the simulated model results, the entire model data quality must be analyzed by calibration and validation technique. Calibration is a process of adjusting the model input data until its results become closely approximate to the measured field data. Whereby, it used to obtain approach, realistic and acceptable results. Therefore, in this study the model data quality analysis was done by comparing and calibrating the computed pressure data with the observed one.

The method of pressure readings was done during March, 2019 using pressure gauge commonly taken both at high and low pressure zone of the selected points in distribution network; such as clear water pump stations, service reservoir, public fountains and different end user taps (like; customers, institution and commercial tap points). These observed pressure data was taken a total of ten (10) samples for both peak demand and low demand (night flow) time analysis. All sampling points were selected after the computed model was simulated and knowing the pressure variation area (pressure zone) in the town water distribution network.

According to Tomas, et al., (2003), the calibration process was performed by adjusting sensitive parameters related with flow; like pipe roughness coefficient and water demand until it was become within the acceptable limit of 85% of field test measurements (it should be within ± 0.5 m or ±5% of the maximum head loss across the system, whichever is greater) and then finally it was validated manually using the correlation coefficient (R^2) method using microsoft Excel sheet.

4. RESULTS AND DISCUSSIONS

4.1. Estimated water demand

Estimating the expected water demand of the town were used for assessing and sizing system components such as pumping station, reservoirs, and transmission and distribution pipe line.

4.1.1. Population forecasting

The water demand of a particular town is proportionally related with the population to be served. The population of Adama town from Ethiopian CSA report, which is carried out in year 2007, was indicated 222,035 and it was used as base population for current estimation. According to CSA, the regional level annual growth rate of urban population for year 2020, 2025 and 2030 were 4.2%, 4.00% and 3.8%, respectively. Based on the above growth rates, the population of Adama Town can be estimated to 547,987 and 803, 38 in the year of 2020 and 2030, respectively.

Using the above CSA (2007) census data as a base, and applying geometric increase population. Forecasting method, the estimated number population from 2011 to 2030 at five (5) years interval for Adama town, Wonji Town and the surrounding village are presented in table 4.1 below.

Table 4. 1: Projected Population of Adama Town, Wonji Town and the surrounding village for the year (2011-2030).

Description	**2011**	**2015**	**2020**	**2025**	**2030**
Population growth Rate	4.36%	4.20%	4.20%	4.00%	3.80%
Adama	271,562	320,140	393,259	478,459	576,543
Wonji Town	75,201	85,080	104,512	127,155	153,222
Rural Villages Residing Town Fringes, along TM & Floating (10%)	34,676	40,879	50,216	61,096	73,620
Total Population	381,440	446,100	547,987	666,710	803,385

4.1.2. Domestic Water Demand

4.1.2.1. Per capital water consumption

The per-capita water consumption for various demand categories varies depending on the size of the town and the level of development. The water demand in Adama Town is high due to socio-economic activity in both governmental and private sectors. Using the daily water consumption and population figures, the average per capital consumption of the town was calculated as shown below (Tomas, et al., 2003).

Per capital consumption (l/c ⁄ d) = Daily consumption (m^3/d ∗ 1000 l/m^3) /Total population ……………………………………………………………………………………4.1

Accordingly, the average per capital consumption of Adama town in the year of 2015, 2020 and 2030 is estimated to be 59.85, 74, 85 and 84, 90 l/c/d, respectively.

4.1.2.2. Average water demand

There are several mathematical methods of estimating the water demands of a given town; including extrapolating historical trends and correlating demand with the socio-economic variables of the town. But, the most common means of forecasting future water demand is estimating current per-capital water consumption, and multiply this by the projected population figure following the formula given below.

Qavg=per capital water consumption*Total population of the town…………….4.2

Accordingly, the average water demand will increased from 14,098m^3/d in 2011 to 42,120 m^3/d in 2030 due the population number and method of connection. Water demand for different type of service levels are summarized in the table below (table 4.2). These includes water demand under different service type such as House Connections (HC); Yard Connections (YC) and Public Fountains (PF).

Table 4. 2: Summary of Domestic Water Demand

No	Town: Adama Description	Unit	2011	2015	2020	2030
1	**Total population**	**No**	**381,440**	**446,100**	**547,987**	**803,385**
	Coverage by service Level					
	HC (house connection)		5.1%	5.1%	10.1%	15.1%
	YC(yard connection)		71.1%	71.1%	65.8%	60.6%
	PF(public fountain)		10.5%	10.5%	24.1%	24.4%
	NC(no connection)		13.3%	13.0%	0.0%	0.0%
	Population served by type of water supply service					
	HC	No	19,453	22,751	55,237	120,909
	YC	No	271,204	317,177	360,740	486,450
	PF	No	40,051	46,840	132,065	196,026
	NC	No	50,731	57,993	0	0
2	**Demand**					
2.1	Domestic					
	Per capita demand					
	HC	l/c/d	60.00	60.00	68.00	75.00
	YC	l/c/d	40.00	40.00	45.00	50.00
	PF	l/c/d	20.00	20.00	23.00	25.00
	Consumption (daily)					
	HC	m^3/d	1,167	1,365	3,756	9,068
	YC	m^3/d	10,848	12,687	16,233	24,322
	PF	m^3/d	801	937	3,037	4,901
	Sub Total		12,816	14,989	23,027	38,291
	Climatic and Socio-Economic factor	combined	1.1	1.1	1.1	1.1
	Total Domestic Demand	**m^3/d**	**14,098**	**16,488**	**25,330**	**42,120**

The different categories of domestic water demand on daily basis for the year 2015, 2020 and 2030 is plotted in the figure below (Figure 4.1), summarizes. This includes Average day demand, Maximum day demand and Peak hourly demand of values by the year of 2015, 2020 and 2025.

4.2. Water distribution network analysis

4.2.1. Nodal Demand Calculation

The Average demand for five zones is tabulated in table 5.4. From the table the maximum and minimum user of demand is located in Lugo and Gelma Aba Gada zone respectively. Both of the zones contain a population of 308,912 and 5,876 respectively.

Table 4. 3: Average Day Demand for Each Zone

No	Zone	Name of Zone	Population		Base Demand(l/s)	
			2015	**2025**	**2015**	**2025**
1	R09EBO-1715	BOKU	24,703	36,217	18.38	27.96
2	RCOL-1725	ADAMA UNIVERSITY	78,907	115,683	58.70	89.32
3	RDHA-1750	DHAKA ADI	27,701	40,612	20.61	31.36
4	RGA-1750	GELMA ABA GADA	5,876	8,615	4.37	6.65
5	RLUGO-1685	LUGO	308,912	452,885	229.80	349.66
TOTAL			446,100	654,011	331.9	504.9

4.2.2. Model Analysis

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

4.2.3. 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. Use appendix for the results.

4.2.4. 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 12:00 AM. The software simulates non-steady-State hydraulic calculation based on mass and energy conservation principle.

The model can be simulated for every hour time setup in the twenty-four hour duration. However, for the analysis the peak and minimum hours, demand has been simulated to identify the current problems of the system and then identify the problem of the model based on the design criteria of the water distribution system, parameters like pressure and velocity.

Use appendix, the attached results of the system performed run from:

- For the minimum hour consumption.
- For the peak hour consumption.

Pipes

The water distribution main model has a total length of **143,623.00m**, which integrates. As depicted in table 5.5, 18.87% of the system contains pipe of 150mm uPVC. This figure is relatively high when compared to 16.55%, 15.88% of 80mm and 200mm uPVC pipe diameter respectively. A single pipe of 250mm uPVC diameter is the lowest.

Table 4. 4: WateCAD data pipe network results

No.	Diameter (mm)	Length (m)	Material Type	Percentage of coverage
1.00	40.00	870	uPVC	8.5
2.00	50.00	10,757.00	uPVC	7.49
3.00	50.00	1,127.00	GI	0.78
4.00	65.00	1,440.00	GI	1.00
5.00	80.00	23,768.00	uPVC	16.55
6.00	100.00	12,812.00	uPVC	8.92
7.00	100.00	1,037.00	DI	0.72
8.00	150.00	27,108.00	uPVC	18.87
9.00	150.00	2,184.00	DI	1.52
10.00	200.00	22,802.00	uPVC	15.88
11.00	200.00	619.00	DI	0.43
12.00	250.00	386.00	uPVC	0.27
13.00	300.00	10,470.00	uPVC	7.29
14.00	300.00	7,501.00	DI	5.22
15.00	400.00	3,304.00	DI	2.30
16.00	500.00	3,875.00	DI	2.70
17.00	600.00	14,433.00	DI	10.05
Total Length		143,623.00		

It is only 0.27% in terms of material type, Polyvinyl chloride (uPVC) pipe is the major pipe. Additionally, the water distribution main model inventory also consists of 800-pressure pipe, 9 reservoir including clear water tank and booster station, 648-junctions and 16-pumps.

4.3. Evaluation of Distribution System

Analysis of the existing distribution network has been conducted for two condition of the peak and minimum demands of the system, as described in the evaluation criteria. The peak hour demand was about 807.1 l/s. It occurs from 6-7 AM in the morning when most people get up for daily business. The existing minimum consumption is 97 l/s. It occurs from 11PM to 3AM hours in the night.

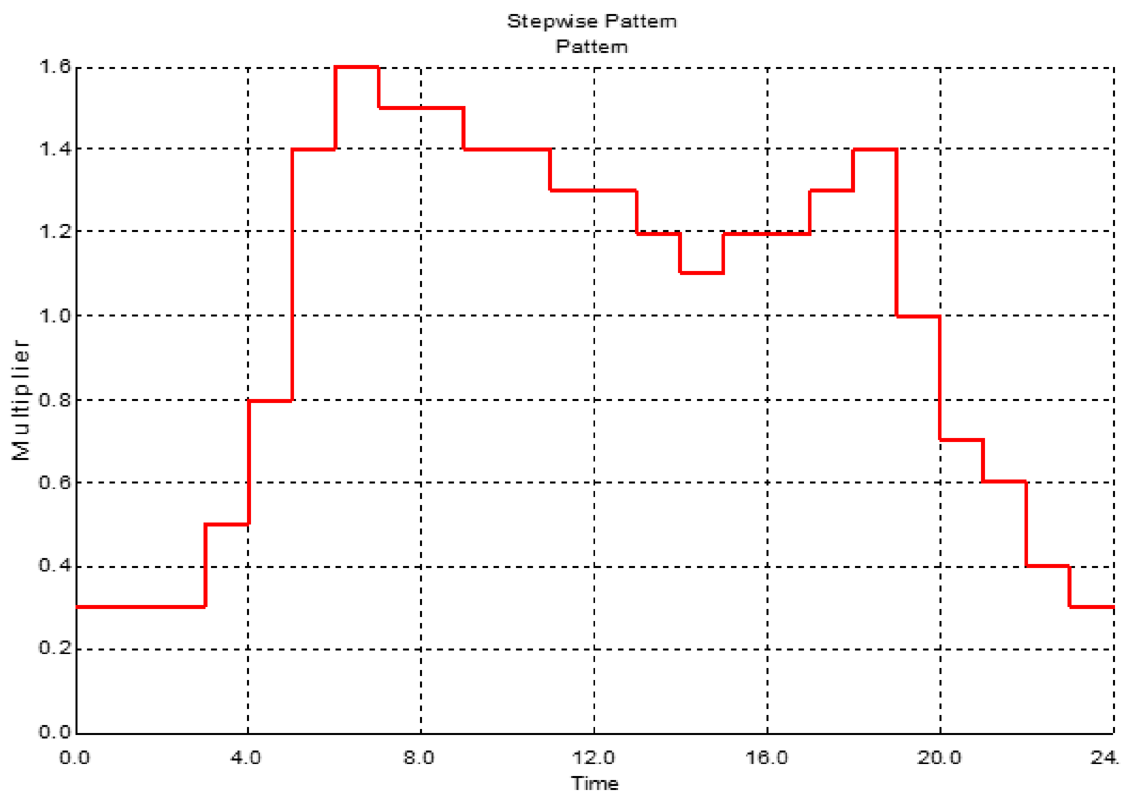


Figure 4. 1: Peak and Minimum Hours Consumption Pattern

Consequently, hydraulic analysis results of the network during Peak and Minimum Hour Demands of the system are summarized as follows.

- The existing distribution system covers around 50% or 2575 ha of the Master Plan area of the town. It has also limited to the central low elevation areas of Adama town, it should be expanded to the elevated areas to solve the current water shortage of the residents.

- Some parts of the network couldn't meet the minimum required pressure of 10 m H2O during the peak hour demand. These are found around Migira and Giko areas, and some parts of Lugo Supply Zone. The pressures are varying from negative 87 to 9 m H2O.

The main reasons for such lower pressures are.

- The installed pipes were small in sizes
- Relatively found on higher ground levels.
- Increased population and water demand.

Undersized pipes can usually be found by looking for pipes with high velocities. Increasing the diameter of the pipe in the model should result in a corresponding decrease in velocity and increase in pressure.

The optimal velocity in pumped lines can range from 1 to 3 m/s, depending on the relative size of the peak and average flow rates [Walski, T.M. (1983). "Energy Efficiency through pipe Design". Journal of the American Water Works Association]. When checking designs for permissible velocities some engineers use 1.5 m/s as a maximum, other use 2.4m/s, and yet still others use 3.1m/s.

Consistent low pressure problem is due to trying to serve customers at too high an elevation for that pressure zone. High pressures are usually caused by serving customers at low elevation for the pressure zone. Usually, high pressures are easiest to evaluate with model runs at low demands. This range corresponds to minimum night time demands for a typical system. If the engineer feels that pressures are too high, the usual solution is to establish a new pressure zone for the lower elevation using PRVs.

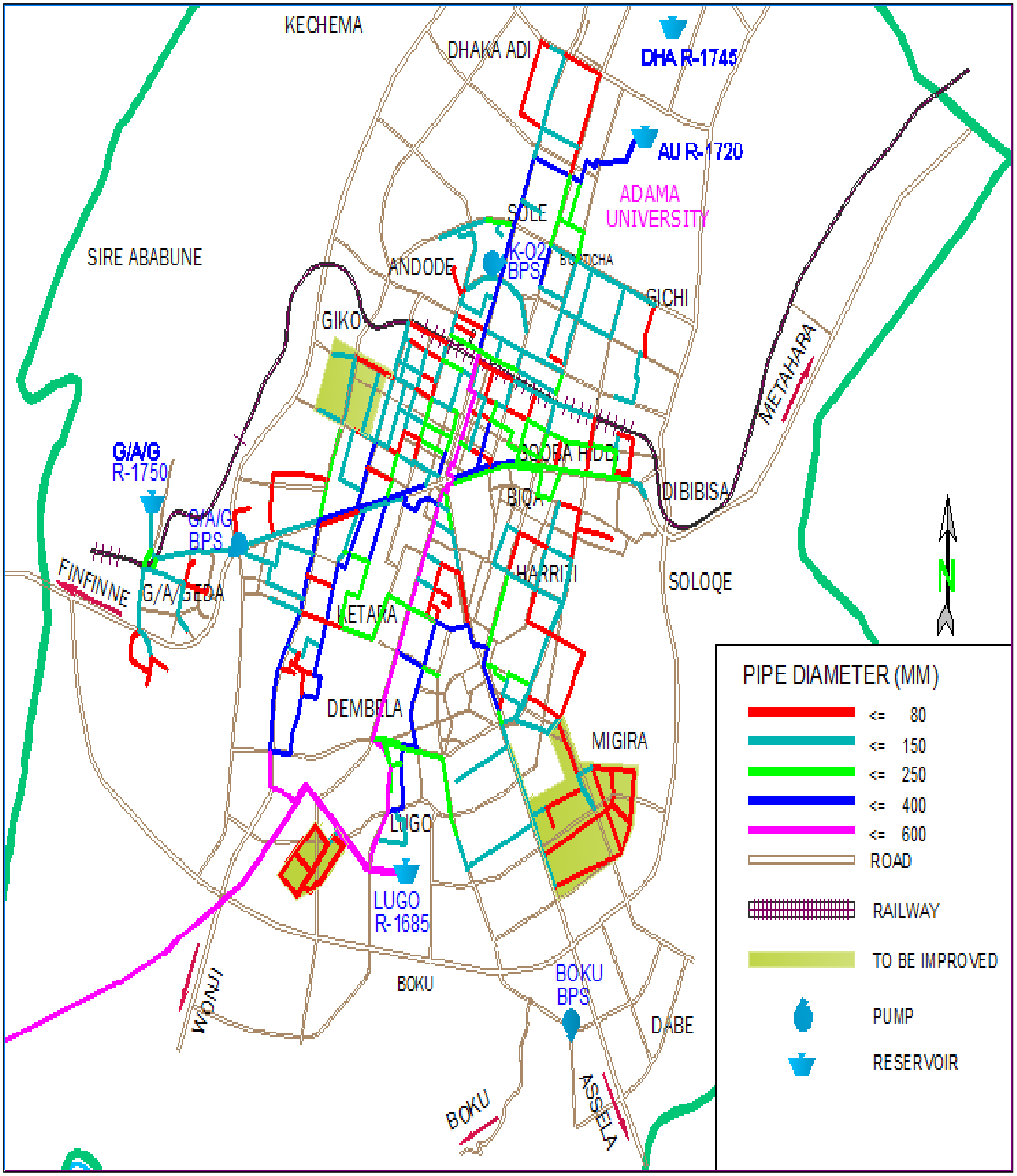


Figure 4. 2: Parts of the Network Requiring Improvement

4.4. Model calibration and validation

The credibility of a model is merely evident if a model result precisely reflects observed field values. Thus, to have a confidence on model result it needs to calibrate and validate a model. The measurements were taken at a location other than the direct connection to the water mains, nearer to the supply main nodes at homes faucet. The locations of the representative samples of a supply main nodes and the corresponding home faucet (field test) are shown in table 4.5. An authorized and calibrated pressure gage taken from AAWSA was used during the field test.

For the calibration, the head loss between the supply main nodes and the site where pressure is measured had been considered. The head loss included the elevation head and pipe friction loss between a two corresponding locations. These head losses and the total head loss are shown in table. At base scenarios of the model, the average head loss gradient is calculated to be 2.4 m/km. These values of head loss gradients have been applied in the calculations pipe length friction loss in the calibration.

Table 4. 5: Locations of the Representative Samples of Supply Main Nodes and the Corresponding Home Faucet.

	Sample Node				corresponding Field Test Measurement Location			Head Loss between sample node and field test location		
S.No	Junction	X	Y	Z	X	Y	Z	Elevation Head(m)	Friction loss(m)	Total Head Loss(m)
1	1.00	529273	945095	1633	529356	945095	1630	3	0.17	3.17
2	2.00	529504	944224	1622	529504	944224	1621	1	0.24	1.24
3	3.00	528061	940774	1633	528003	940708	1624	9	1.21	10.21
4	4.00	528692	944962	1631	528638	944982	1630	1	0.36	1.36
5	5.00	527383	943496	1634	527530	943533	1632	2	1.16	3.16
6	6.00	531123	943573	1605	531103	943492	1606	1	0.23	1.23
7	7.00	530064	944168	1627	530064	944167	1625	2	1.7	3.7
8	8.00	530510	945300	1640.5	530510	945300	1640	0.5	0.19	0.69
9	9.00	529581	942668	1617	529656	942685	1622	5	0.73	5.73
10	10.00	528208	942698	1613	528207	942697	1614	1	0.11	1.11

As a result, almost 100% of the field test measurements were within ± 2 m, showing an acceptable level of pressure calibration criteria. The comparison of model simulated and field test are shown table and figure. The calibrations have been carried for the base scenarios, for the model validation. Calibrations base scenarios were within the acceptable level. Hence, the model is valid for the scenarios.

4.4.1. Model Validation

The model validation work was carried out using Microsoft excel at 95% level of confidence.

$$R^2 = \frac{\sum(x-x_{avg})(y-y_{avg})}{\sqrt{\sum(x-x_{avg})^2\sum(y-y_{avg})^2}} \quad \text{..........} 4.3$$

Where: R^2 = correlation coefficient, X and Y are the observed and computed pressure values, and x_{avg} and y_{avg} are mean value of observed and computed pressure, respectively. As shown in figure 4.5, the results of correlation value (R^2) for the correlation between observed and simulated pressure was 97% at 95% level of confidence. Thereby, the calibrated pressure value was validated within the recommended standard.

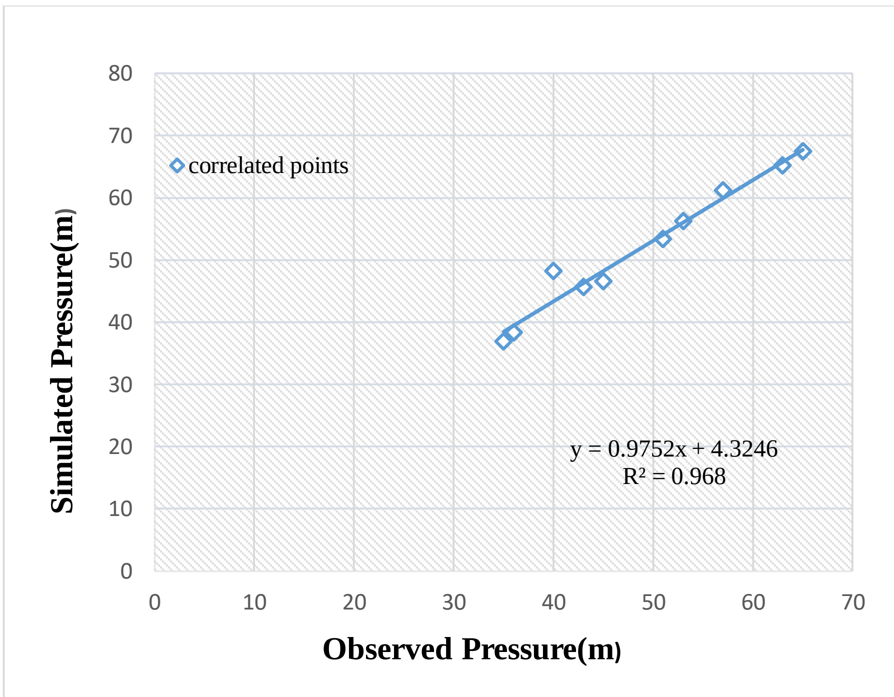


Figure 4. 3: Correlation of Observed and Simulated Pressure

4.4.2. 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. Whereby, water loss for Adama Town was assessed and discussed as below;

4.4.3. Percentage of water loss

Non-Revenue Water includes water losses in the water distribution system, illegal connections, and improper metering and recording. The amount is expressed as percentage of the total produced water from the water supply system. The percentage usually varies and depending on the age of the pipes and complexity of the system. It has been stated that the apparent water loss accounts about 20% of the total water losses (Seago et al, 2005). Unaccounted water loss is the sum of real loss and apparent losses. It was found that unaccounted water losses estimated for the year 2015, 2020 and 2030 would be 3617m3/d, 5557m3/d and 9241 m3/d, respectively. This loss accounts 21.9% of the total daily water demand of Adama Town in the predicted years.

Water losses can be either real (physical) losses or apparent losses. Real losses are mainly due to leakage from joints in water pipes, service connections, pipe bursts, pipe cracks and overflows from storage tanks. As evidenced during the field visit the main cause of water losses for Adama Town seems more likely due to operation and maintenance of distribution network such pipe bursts and pipe cracks. Due to installation of under size pipe system, the pressure becomes beyond permissible limit in the distribution system at the minimum consumption period.

Figure 4. 4: Maintenance of Pipe Burst Observed During Field Visit.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The research project focused to know water supply coverage, model hydraulic, and to evaluate the distribution system, and resulted in the following key achievements:

- Shortage of service pressure at different junction due to topographic and size of pipes.
- Unaccounted for water has been increasing from 13.43% to 45.46% of water production.
- Pressure based hydraulic performance evaluation indicated that acceptable minimum pressure value has not been met. During peak hour 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 possibly attributed by zonal topography which require addition boosting tank. These are found around **Migira** and **Giko** areas, and are parts of **Lugo Supply Zone**. The pressures are varying from negative 87 to 9 m H2O.
- Although the pressure in most distribution is below the standard, we were observed high pressure greater than 80 m from the model out in some distribution which probably attributed due to under sized pipe installation.
- Most parts of the central network being suffered by lower flow velocities of less than 0.5m/s due to unnecessarily congestion of pipe network. This is to the extent of occurring zero (no) flow conditions in some of the pipes.
- Besides, there is no alternative water source for emergency case; if supply fails from Awash River, water supply situation is becoming worst in the town due to lack of emergency water supply source.
- In general, the simulated hydraulic result indicated that the current hydraulic performance of Adama town distribution system is not satisfactory. But it doesn't mean that the system is not functional. Rather the frequency of service interruption is relatively high. This interruption is partly contributing for the current water shortage in the town.

5.2. Recommendation

- The existing distribution system is limited to the central lowlands of Adama town; it should be expanded to the highland areas to solve the current water shortage of the town.
- It is most recommended that the areas located at the low pressure (higher ground level), needs additional pressure tanks or new pressure zone by pumping the water from the nearest booster pumps to solve the problems of poor pressures at the area. On the other hand, under sized pipe needs to be replaced to standard size.
- WaterCAD is a commonly used network simulation tool. Other hydraulic network solvers such as EPANET, H_2ONET etc. should be considered in the water distribution network performance and compared with that of WaterCAD.
- Pressure readings need to be taken at more than ten locations to verify the result of the simulation to increase the accuracy of the model.
- The entire pump installed at clear water tank and booster stations must be changed or increased to pump the future demand.
- ATWSSE should gather the X, Y, coordinates of its customer water meters to make a model using Water CAD with GIS integrated software, for more precise and faster way of modeling in demand allocation. Each customer account assigned an x-y coordinate in a GIS. Then, each account can be assigned to a node in the model based on polygons around each node in the GIS. By querying the customer information database, the average demand at each node for any billing period can be determined. The billing data must now be corrected for unaccounted-for water. When working with high-quality GIS data, the modeler can much more precisely assign demands to nodes.
- The deficit of water supply in the system should be reduced by minimizing the large amount of unaccounted for water.
- The town water supply and sanitation enterprise should think to install the **SCADA NETWORK SYTEM** to manage and control the whole water supply system network including the issue of water loss.
- In this study water quality was not analyzed due to time and financial constraints, hence the future research should give attention for better performance evaluation.

References

1. AWWA manual M32, Distribution Network Analysis for Water Utilities.
2. Bentley Water CAD/GEMs (2008): "Water Distribution Design and Modeling, Full Version V8i".
3. Chambers, K., Creasey, J. & Forbes, L. (2004). Design and Operation of Water Distribution Networks:
4. CSA (2007): Central Statistical Agency of Ethiopia
5. Haestad Methods.(1999), "Computer Applications in Hydraulic Engineering", Student Edition, Second Edition, Haestad Press, Inc.
6. Japan Water works Association (1990): Design Criteria for Water works Facilities.
7. Jeffrey A. Gilbert, P.E. (2012). Practical Design of Water Distribution Systems.
8. Ministry of water resource (2006): Urban water supply design criteria.
9. MoWR (2006): Detail design and tender document preparation of Negele area long range water supply project, unpublished.
10. Neha Mangesh Bhadbhade (2009). "Water Distribution System Using Hydraulic Simulation Software for the City of Oilton, Oklahoma".
11. OWWDSE (2011): Adama Town Water supply Feasibility study.
12. OWRB (Oromia Water Resources Bureaus), (2008), Three Years UAP Performance Reports and Revised Regional Strategic Plans.
13. Shaher Hussni Abdul Razaq Zyroud (2003). "Hydraulic Performance of Palestinian Water Distribution Systems".
14. Steel, E.W. and McGhee, T.J. (1979). "Water Supply and Sewerage". Fifth Edition, McGraw-Hill International Book Company, U.S.A.
15. Swamee, Prabhata K. (Prabhata Kumar), 1940, Design of water supply pipe networks Prabhata K. Swamee, Ashok K. Sharma.
16. Thomas M.Walski, Donald V. Chase, Dragan A. Savic, Walter Grayman, Stephan Beckwith, Edmundo Koelle (2003). "Advanced Water Distribution Modeling and Management", US. Haestad Press. Waterbury, CT USA.

17. Walski, T.M. (1983). "Energy Efficiency through pipe Design". Journal of the American

18. Walski, T., William, B., Emanuel, T. P., Mark, Weir. and Brain, E.W. (2006): "Modeling Leakage Reduction through Pressure Control" 98:4. Journal AWWA.

19. Wallingford HR., 2003, Handbook for the Assessment of Catchments Water Demand and Use

20. Welday Berhe Desalegn (2005). "Water Supply Coverage and Water loss in Distribution Systems, The Case of Addis Ababa)".

21. WHO (2004): Managing Microbial Water Quality in Piped Distribution Systems. Safe Piped Water.Water works Association.

Appendices

Appendix 1: Summary of Total Water Demand and Coverage

No	City: Adama				
	Description	**Unit**	**2015**	**2020**	**2030**
1	**Total Population**	**No**	**446,100**	**547,987**	**803,385**
2	**Total Water Demand**	**m^3/d**	**26,700**	**41,019**	**68,210**
	Domestic Demand	m^3/d	16,488	25,330	42,120
	Public and Commercial (20 to 40%)=30%	m^3/d	4,946	7,599	12,636
	Industrial Demand (10%)	m^3/d	1,649	2,533	4,212
	Un-Accounted For Water(21.94%) average		3,617	5,557	9,241
		%	21.9%	21.9%	21.9%
3.1	**Avg Day Demand (ADD)**	**m^3/d**	**26,700**	**41,019**	**68,210**
		l/s	**309.0**	**474.8**	**789.5**
	Maximum Day Factor		1.2	1.2	1.2
3.2	**Maximum Day Demand (MDD) -**	**m^3/d**	**32,040**	**49,223**	**81,852**
		l/s	**370.8**	**569.7**	**947.4**
	Peak hour Factor		1.7	1.7	1.7
3.3	**Peak hour Demand**	**l/s**	**525.4**	**807.1**	**1342.1**

Appendix 2: PDD extended Simulation

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
531,561	941,133	1,603	RLUGO-1685	1.60	-87.05
531,579	941,220	1,603	RLUGO-1685	-	-83.73
531,489	941,084	1,600	RLUGO-1685	6.40	-80.57
531,571	941,307	1,597	RLUGO-1685	-	-74.84
531,558	941,391	1,594	RLUGO-1685	-	-69.01
531,538	941,439	1,594	RLUGO-1685	1.60	-66.29
531,318	941,449	1,597	RLUGO-1685	1.60	-57.08
530,855	940,398	1,612	RLUGO-1685	9.10	-56.75
531,141	941,382	1,598	RLUGO-1685	1.90	-55.41
531,350	941,093	1,596	RLUGO-1685	5.20	-54.38
531,199	941,269	1,595	RLUGO-1685	1.90	-52.31
530,727	940,683	1,606	RLUGO-1685	8.80	-42.36
528,398	945,080	1,636	RLUGO-1685	2.70	-39.88
528,129	945,101	1,635	RLUGO-1685	5.60	-39.66
527,950	944,605	1,627	RLUGO-1685	5.60	-38.99
528,266	944,578	1,626	RLUGO-1685	0.70	-36.73
528,237	944,498	1,624	RLUGO-1685	0.70	-34.92
530,847	940,934	1,601	RLUGO-1685	5.10	-13.42
530,754	941,097	1,599	RLUGO-1685	-	-7.5
528,855	940,791	1,683	RLUGO-1685	0.60	-1.94
528,974	940,536	1,683	RLUGO-1685	-	1.68
530,194	945,920	1,657	RDHA-1750	-	1.98
530,200	945,918	1,657	RCOL-1725	-	1.99

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
530,200	945,917	1,657	RCOL-1725	-	1.99
530,200	945,919	1,657	RCOL-1725	-	1.99
528,897	940,535	1,682	RLUGO-1685	1.40	2.44
530,200	945,920	1,656	RCOL-1725	-	2.99
525,885	943,728	1,754	R01SA-1800	-	3.09
530,571	941,027	1,601	RLUGO-1685	5.10	3.77
529,008	940,771	1,677	RLUGO-1685	1.30	3.91
531,127	937,829	1,712	R09EBO-1715	-	3.98
531,119	937,829	1,713	R09EBO-1715	-	4.02
531,239	939,461	1,632	R09EBO-1715	-	5.6
531,840	946,981	1,714	RCOL-1725	-	7.29
531,414	947,558	1,702	RCOL-1725	4.30	8.42
525,890	943,752	1,748	RGA-1750	-	9.33
532,301	947,852	1,737	RDHA-1750	-	9.41
528,585	940,558	1,672	RLUGO-1685	1.50	9.87
528,618	940,553	1,673	RLUGO-1685	-	9.93
525,889	943,727	1,747	RGA-1750	-	10.06
528,713	940,803	1,670	RLUGO-1685	-	11.16
525,886	943,693	1,746	RGA-1750	-	11.16
528,566	940,561	1,671	RLUGO-1685	-	11.18
528,590	940,681	1,670	RLUGO-1685	1.50	12.2
525,884	943,652	1,744	RGA-1750	-	13.08
528,612	940,750	1,668	RLUGO-1685	-	13.55

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
530,227	945,880	1,659	RLUGO-1685	-	14.17
530,205	945,888	1,658	RLUGO-1685	-	14.56
528,662	940,832	1,666	RLUGO-1685	0.60	15.86
525,883	943,615	1,741	RGA-1750	-	15.93
531,057	939,881	1,625	RLUGO-1685	-	16.9
530,998	947,726	1,693	RCOL-1725	-	17.6
525,881	943,581	1,739	RGA-1750	-	17.75
528,692	944,962	1,631	RLUGO-1685	2.00	18.25
531,736	946,806	1,702	RCOL-1725	8.10	18.89
531,119	938,090	1,700	R09EBO-1715	-	19.43
530,105	945,765	1,654	RLUGO-1685	-	19.47
528,920	940,992	1,660	RLUGO-1685	-	20.24
525,880	943,543	1,736	RGA-1750	-	20.47
528,999	941,003	1,659	RLUGO-1685	1.20	21.39
529,854	946,160	1,651	RLUGO-1685	-	21.73
525,882	943,513	1,735	RGA-1750	-	21.81
530,300	945,704	1,651	RLUGO-1685	0.20	22.15
527,089	943,742	1,642	RLUGO-1685	0.90	22.26
529,684	946,136	1,650	RLUGO-1685	0.80	22.7
530,175	945,752	1,650	RLUGO-1685	1.90	23.04
525,870	943,359	1,734	R01SA-1800	-	23.29
526,900	943,704	1,642	RLUGO-1685	0.90	23.58
528,791	941,071	1,657	RLUGO-1685	1.20	23.79

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
530,827	947,413	1,689	RCOL-1725	2.60	24
531,123	938,272	1,691	R09EBO-1715	-	24.47
529,627	945,853	1,644	RLUGO-1685	0.60	24.53
530,683	947,854	1,685	RCOL-1725	2.50	24.6
529,993	945,764	1,648	RLUGO-1685	-	25.1
529,595	945,837	1,644	RLUGO-1685	0.60	25.19
530,778	947,815	1,685	RCOL-1725	1.40	25.19
525,881	943,463	1,732	RGA-1750	-	25.4
529,878	946,027	1,647	RLUGO-1685	1.70	25.44
526,944	943,394	1,649	RLUGO-1685	0.90	25.62
532,283	947,681	1,720	RDHA-1750	-	26.53
532,271	947,664	1,720	RDHA-1750	-	26.6
530,006	945,622	1,646	RLUGO-1685	0.40	27.19
529,642	941,343	1,615	RLUGO-1685	2.90	27.38
530,428	945,580	1,645	RLUGO-1685	0.20	27.4
530,108	945,583	1,646	RLUGO-1685	1.40	27.57
524,969	942,909	1,728	RGA-1750	0.90	27.78
530,878	940,277	1,616	RLUGO-1685	-	28.24
525,879	943,399	1,728	RGA-1750	-	28.93
531,999	947,356	1,718	RDHA-1750	-	29
530,495	945,397	1,642	RLUGO-1685	0.40	29.35
528,904	941,089	1,651	RLUGO-1685	1.20	29.41
529,875	945,724	1,644	RLUGO-1685	-	29.45

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
531,118	938,272	1,691	R09EBO-1715	-	29.66
529,687	945,649	1,642	RLUGO-1685	-	30.03
528,988	941,105	1,650	RLUGO-1685	-	30.49
527,039	943,337	1,644	RLUGO-1685	0.90	30.75
532,826	947,227	1,716	RDHA-1750	-	30.88
530,510	945,300	1,640	RLUGO-1685	2.70	31.03
533,282	947,952	1,715	RDHA-1750	-	31.16
532,115	947,310	1,715	RDHA-1750	-	31.59
531,954	947,341	1,715	RDHA-1750	-	31.71
532,898	947,359	1,715	RDHA-1750	-	31.73
529,939	945,444	1,641	RLUGO-1685	1.40	31.83
532,258	947,564	1,714	RDHA-1750	-	31.92
525,806	943,236	1,725	R01SA-1800	-	31.95
525,878	943,358	1,725	RGA-1750	-	31.99
532,250	947,522	1,714	RDHA-1750	-	32.38
530,702	947,099	1,685	RCOL-1725	2.30	32.41
529,814	945,493	1,640	RLUGO-1685	-	32.55
531,888	947,402	1,714	RDHA-1750	-	32.81
531,436	946,785	1,687	RCOL-1725	8.10	32.93
527,339	942,948	1,632	RLUGO-1685	10.80	33.34
529,784	945,665	1,640	RLUGO-1685	-	33.41
527,062	943,421	1,642	RLUGO-1685	0.40	33.51
531,374	946,810	1,686	RCOL-1725	-	33.67

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
531,887	947,778	1,713	RDHA-1750	-	33.76
531,885	947,171	1,713	RDHA-1750	-	33.83
529,739	945,670	1,639	RLUGO-1685	0.90	34.19
529,697	945,558	1,639	RLUGO-1685	-	34.35
525,890	943,345	1,722	RGA-1750	-	34.87
529,721	945,624	1,638	RLUGO-1685	0.90	34.95
528,807	941,256	1,645	RLUGO-1685	-	35.15
525,893	943,341	1,722	RGA-1750	-	35.35
531,352	946,752	1,684	RCOL-1725	2.90	35.44
530,446	947,275	1,675	RCOL-1725	-	35.5
531,844	947,072	1,711	RDHA-1750	-	35.59
530,952	944,935	1,638	RLUGO-1685	6.30	35.64
529,649	945,451	1,639	RLUGO-1685	0.80	35.71
531,648	947,915	1,711	RDHA-1750	-	35.82
528,825	941,260	1,644	RLUGO-1685	-	35.91
532,152	947,294	1,711	RDHA-1750	-	36.16
530,435	947,228	1,674	RCOL-1725	4.10	36.56
528,827	941,318	1,643	RLUGO-1685	-	36.7
525,784	943,199	1,720	RGA-1750	0.20	36.79
529,049	945,380	1,638	RLUGO-1685	0.90	36.8
530,202	945,232	1,637	RLUGO-1685	0.60	37.02
532,198	947,304	1,710	RDHA-1750	-	37.12
530,003	945,312	1,637	RLUGO-1685	0.40	37.14

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
531,682	938,531	1,679	R09EBO-1715	-	37.31
528,252	940,754	1,641	RLUGO-1685	0.30	37.7
530,450	945,135	1,636	RLUGO-1685	5.90	37.73
532,193	947,282	1,709	RDHA-1750	-	37.74
532,192	947,279	1,709	RDHA-1750	-	37.82
530,272	943,583	1,621	RLUGO-1685	2.00	38.3
531,151	946,920	1,678	RCOL-1725	3.60	38.36
527,339	943,716	1,635	RLUGO-1685	1.30	38.38
527,350	943,631	1,636	RLUGO-1685	-	38.45
529,616	945,358	1,636	RLUGO-1685	0.40	38.45
530,742	940,575	1,609	RLUGO-1685	-	38.5
529,822	942,607	1,629	RLUGO-1685	-	38.53
525,898	943,335	1,718	RGA-1750	-	38.61
531,047	942,121	1,599	RLUGO-1685	1.80	38.64
531,321	947,635	1,709	RDHA-1750	-	38.66
528,993	945,237	1,636	RLUGO-1685	0.40	38.71
530,490	947,187	1,673	RCOL-1725	-	38.78
525,798	943,203	1,718	R01SA-1800	-	38.78
532,035	948,454	1,707	RDHA-1750	-	38.92
531,238	946,799	1,681	RCOL-1725	0.50	39.11
531,117	942,289	1,599	RLUGO-1685	-	39.13
532,192	947,244	1,707	RDHA-1750	-	39.29
525,822	942,571	1,717	RGA-1750	-	39.29

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
529,076	945,205	1,635	RLUGO-1685	0.50	39.58
530,891	941,862	1,598	RLUGO-1685	1.60	39.76
530,098	943,251	1,621	RLUGO-1685	2.50	39.78
529,853	945,267	1,634	RLUGO-1685	0.40	39.94
529,898	945,046	1,635	RLUGO-1685	0.60	40
530,932	941,901	1,597	RLUGO-1685	-	40.05
525,884	942,421	1,716	RGA-1750	0.40	40.15
525,801	942,624	1,716	RGA-1750	0.20	40.34
530,289	941,647	1,602	RLUGO-1685	5.30	40.36
525,913	943,319	1,717	RGA-1750	-	40.36
529,930	945,127	1,634	RLUGO-1685	0.40	40.54
528,840	941,458	1,638	RLUGO-1685	-	40.63
529,860	942,519	1,626	RLUGO-1685	1.10	40.69
530,875	944,760	1,633	RLUGO-1685	-	40.72
527,314	943,076	1,636	RLUGO-1685	0.70	40.73
530,379	944,953	1,633	RLUGO-1685	1.00	40.74
529,580	945,264	1,634	RLUGO-1685	0.70	40.89
527,360	943,249	1,635	RLUGO-1685	0.70	40.93
528,824	941,461	1,639	RLUGO-1685	1.10	41.01
527,383	943,496	1,634	RLUGO-1685	1.30	41.03
529,899	942,529	1,625	RLUGO-1685	-	41.24
528,839	941,464	1,638	RLUGO-1685	1.10	41.41
527,384	944,038	1,631	RLUGO-1685	2.30	41.56

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
529,273	945,128	1,633	RLUGO-1685	0.70	41.62
528,915	945,039	1,632	RLUGO-1685	0.40	42.02
529,789	942,715	1,627	RLUGO-1685	1.10	42.35
531,211	942,456	1,597	RLUGO-1685	3.20	42.39
527,418	943,233	1,634	RLUGO-1685	0.70	42.45
531,716	947,472	1,704	RDHA-1750	-	42.91
530,131	945,049	1,631	RLUGO-1685	0.60	42.97
525,811	943,200	1,713	RGA-1750	-	43.35
527,918	940,445	1,633	RLUGO-1685	-	43.39
527,472	943,437	1,633	RLUGO-1685	0.70	43.42
527,933	940,424	1,633	RLUGO-1685	1.30	43.48
530,777	941,760	1,598	RLUGO-1685	1.60	43.49
529,771	940,565	1,620	RLUGO-1685	2.70	43.52
529,472	945,049	1,631	RLUGO-1685	0.80	43.78
530,599	946,836	1,676	RCOL-1725	2.70	43.84
529,531	945,198	1,630	RLUGO-1685	1.10	43.91
531,551	947,541	1,703	RDHA-1750	-	43.92
530,342	944,867	1,631	RLUGO-1685	0.90	43.98
525,694	942,376	1,712	RGA-1750	-	44.01
529,707	944,952	1,630	RLUGO-1685	0.70	44.08
528,996	945,005	1,630	RLUGO-1685	0.50	44.13
530,616	944,762	1,631	RLUGO-1685	0.90	44.42
525,771	943,143	1,712	RGA-1750	-	44.63

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
528,911	942,465	1,633	RLUGO-1685	3.80	44.65
525,929	943,299	1,712	RGA-1750	-	44.7
528,061	940,774	1,634	RLUGO-1685	0.70	44.72
529,841	944,899	1,630	RLUGO-1685	0.50	44.73
528,860	944,899	1,630	RLUGO-1685	1.00	44.84
531,084	942,513	1,598	RLUGO-1685	1.80	44.95
531,691	947,455	1,701	RDHA-1750	-	44.98
525,645	942,403	1,711	RGA-1750	-	45.09
531,221	943,535	1,606	RLUGO-1685	0.60	45.12
530,333	944,416	1,630	RLUGO-1685	1.10	45.37
531,634	947,273	1,701	RDHA-1750	-	45.48
531,173	946,619	1,674	RCOL-1725	0.90	45.63
531,159	943,717	1,607	RLUGO-1685	1.10	45.75
530,681	941,796	1,599	RLUGO-1685	-	45.82
525,865	943,197	1,711	RGA-1750	0.40	45.83
528,962	941,481	1,633	RLUGO-1685	1.40	45.94
530,863	944,665	1,629	RLUGO-1685	1.30	46.06
529,995	944,712	1,629	RLUGO-1685	0.50	46.19
529,197	944,927	1,628	RLUGO-1685	1.10	46.19
527,849	940,531	1,630	RLUGO-1685	0.70	46.24
529,877	944,759	1,628	RLUGO-1685	0.50	46.38
530,905	943,787	1,608	RLUGO-1685	1.00	46.4
527,479	943,022	1,630	RLUGO-1685	0.80	46.41

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
527,838	940,360	1,630	RLUGO-1685	0.40	46.44
531,109	947,720	1,701	RDHA-1750	-	46.49
525,887	943,222	1,710	RGA-1750	-	46.54
531,384	943,523	1,604	RLUGO-1685	1.10	46.65
530,289	944,304	1,629	RLUGO-1685	-	46.65
528,941	944,867	1,628	RLUGO-1685	0.30	46.74
525,750	942,998	1,710	RGA-1750	-	46.84
531,123	943,573	1,605	RLUGO-1685	1.10	46.89
529,391	944,850	1,627	RLUGO-1685	0.70	46.91
530,099	944,965	1,628	RLUGO-1685	0.10	46.92
530,133	944,673	1,628	RLUGO-1685	0.20	46.95
531,449	947,581	1,700	RDHA-1750	-	46.98
525,829	942,178	1,709	RGA-1750	0.40	47.01
525,889	943,188	1,710	RGA-1750	-	47.01
525,760	943,063	1,710	RGA-1750	-	47.02
529,852	940,604	1,615	RLUGO-1685	-	47.09
531,566	943,468	1,603	RLUGO-1685	1.10	47.35
530,128	944,659	1,628	RLUGO-1685	0.20	47.38
527,710	944,044	1,625	RLUGO-1685	2.30	47.45
529,798	944,789	1,627	RLUGO-1685	-	47.58
531,051	946,666	1,672	RCOL-1725	2.00	47.76
530,246	944,627	1,628	RLUGO-1685	0.80	47.77
530,423	943,523	1,612	RLUGO-1685	2.00	47.96

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
530,464	940,890	1,604	RLUGO-1685	-	47.97
530,290	943,178	1,613	RLUGO-1685	-	47.98
530,285	943,165	1,613	RLUGO-1685	2.50	47.99
530,525	944,518	1,627	RLUGO-1685	1.00	47.99
529,063	941,613	1,627	RLUGO-1685	-	48.03
530,578	940,943	1,602	RLUGO-1685	6.90	48.06
531,051	943,286	1,606	RLUGO-1685	2.20	48.53
528,124	940,852	1,631	RLUGO-1685	0.30	48.54
529,335	944,711	1,626	RLUGO-1685	0.70	48.67
530,760	943,395	1,606	RLUGO-1685	2.40	48.67
528,375	944,440	1,627	RLUGO-1685	0.60	48.68
531,906	945,107	1,641	RCOL-1725	1.60	48.68
529,018	944,837	1,626	RLUGO-1685	0.30	48.74
529,602	944,702	1,626	RLUGO-1685	0.70	48.76
529,069	942,868	1,628	RLUGO-1685	1.80	48.82
529,656	944,585	1,625	RLUGO-1685	6.50	48.9
530,064	944,168	1,627	RLUGO-1685	0.40	48.93
528,189	940,928	1,632	RLUGO-1685	3.00	48.96
525,951	943,177	1,708	RGA-1750	-	49.01
530,606	942,043	1,602	RLUGO-1685	1.50	49.1
525,940	943,281	1,708	RGA-1750	-	49.14
529,144	944,788	1,625	RLUGO-1685	0.60	49.21
526,313	942,671	1,707	RGA-1750	1.90	49.32

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
529,811	944,609	1,626	RLUGO-1685	5.30	49.4
529,938	944,218	1,626	RLUGO-1685	0.60	49.48
530,434	944,275	1,626	RLUGO-1685	1.10	49.48
525,946	943,284	1,707	RGA-1750	-	49.51
530,037	944,106	1,626	RLUGO-1685	0.10	49.53
530,425	944,252	1,626	RLUGO-1685	-	49.68
526,396	943,262	1,706	RGA-1750	0.50	49.77
530,059	944,518	1,625	RLUGO-1685	0.40	50.04
529,934	944,558	1,625	RLUGO-1685	0.60	50.06
529,945	944,554	1,625	RLUGO-1685	-	50.09
529,949	944,564	1,625	RLUGO-1685	-	50.12
530,069	944,514	1,625	RLUGO-1685	0.40	50.17
525,623	942,413	1,706	RGA-1750	0.20	50.18
530,147	944,091	1,625	RLUGO-1685	0.50	50.24
526,218	942,792	1,706	RGA-1750	-	50.33
529,274	941,572	1,624	RLUGO-1685	-	50.33
530,201	944,136	1,625	RLUGO-1685	0.20	50.44
525,728	942,848	1,706	RGA-1750	-	50.44
528,745	941,678	1,627	RLUGO-1685	-	50.48
530,031	942,497	1,614	RLUGO-1685	2.70	50.52
531,966	945,083	1,639	RCOL-1725	1.60	50.62
525,774	942,333	1,705	RGA-1750	-	50.66
529,248	943,334	1,626	RLUGO-1685	1.30	50.77

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
529,514	944,220	1,624	RLUGO-1685	0.40	50.82
525,942	943,284	1,706	RGA-1750	0.40	50.88
530,455	941,841	1,602	RLUGO-1685	-	50.95
530,318	944,150	1,624	RLUGO-1685	-	51.03
529,504	944,224	1,623	RLUGO-1685	0.40	51.18
528,752	941,623	1,628	RLUGO-1685	-	51.24
528,740	941,703	1,628	RLUGO-1685	1.10	51.24
529,812	944,268	1,624	RLUGO-1685	0.70	51.27
528,471	944,401	1,623	RLUGO-1685	0.60	51.35
529,552	944,625	1,623	RLUGO-1685	0.50	51.37
530,255	944,111	1,624	RLUGO-1685	-	51.46
529,977	942,355	1,612	RLUGO-1685	0.70	51.47
529,985	942,376	1,612	RLUGO-1685	-	51.51
525,726	942,800	1,705	RGA-1750	-	51.55
529,426	944,021	1,623	RLUGO-1685	0.40	51.56
529,853	944,026	1,624	RLUGO-1685	0.70	51.62
525,993	943,161	1,705	RGA-1750	-	51.76
528,985	941,654	1,627	RLUGO-1685	1.40	51.81
527,676	940,314	1,623	RLUGO-1685	0.90	51.87
525,984	943,291	1,705	RGA-1750	-	51.91
529,653	940,823	1,617	RLUGO-1685	1.20	51.94
530,391	941,852	1,603	RLUGO-1685	-	52
530,386	944,148	1,623	RLUGO-1685	0.20	52.08

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
529,130	943,717	1,624	RLUGO-1685	0.70	52.12
529,247	944,488	1,622	RLUGO-1685	0.90	52.14
529,690	944,315	1,623	RLUGO-1685	0.60	52.14
530,325	944,113	1,623	RLUGO-1685	0.60	52.25
526,080	942,315	1,703	RGA-1750	0.50	52.31
530,998	947,678	1,695	RDHA-1750	-	52.33
529,054	944,563	1,622	RLUGO-1685	0.60	52.37
529,321	944,063	1,623	RLUGO-1685	0.40	52.38
531,973	945,263	1,645	RCOL-1725	-	52.43
531,218	946,177	1,664	RCOL-1725	8.10	52.45
528,641	944,336	1,623	RLUGO-1685	1.30	52.48
527,864	943,337	1,624	RLUGO-1685	1.70	52.48
528,931	944,612	1,622	RLUGO-1685	0.80	52.51
528,999	944,421	1,622	RLUGO-1685	-	52.51
529,569	944,133	1,623	RLUGO-1685	0.20	52.64
529,144	941,623	1,626	RLUGO-1685	1.40	52.65
532,088	945,538	1,657	RCOL-1725	2.80	52.7
529,608	944,117	1,623	RLUGO-1685	0.20	52.7
529,568	944,363	1,622	RLUGO-1685	0.80	52.71
527,713	942,828	1,624	RLUGO-1685	2.30	52.72
531,028	946,247	1,665	RCOL-1725	1.10	52.81
529,364	943,622	1,624	RLUGO-1685	1.10	52.84
531,013	947,732	1,693	RDHA-1750	-	53.01

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
530,683	946,354	1,667	RCOL-1725	1.50	53.16
526,347	943,236	1,703	RGA-1750	-	53.19
529,277	942,786	1,622	RLUGO-1685	0.70	53.2
531,354	944,531	1,622	RLUGO-1685	1.30	53.22
529,620	943,968	1,623	RLUGO-1685	0.50	53.29
528,207	944,001	1,622	RLUGO-1685	1.10	53.33
531,019	947,713	1,694	RDHA-1750	-	53.33
529,193	944,346	1,621	RLUGO-1685	0.90	53.34
529,206	943,808	1,623	RLUGO-1685	-	53.36
530,448	946,449	1,667	RCOL-1725	1.90	53.44
529,886	944,073	1,622	RLUGO-1685	0.40	53.53
529,162	943,111	1,623	RLUGO-1685	1.10	53.55
530,515	942,747	1,599	RLUGO-1685	2.30	53.61
529,089	941,931	1,624	RLUGO-1685	-	53.81
530,818	942,615	1,601	RLUGO-1685	-	53.83
525,626	942,470	1,702	RGA-1750	-	53.85
529,317	942,886	1,621	RLUGO-1685	-	53.91
527,759	940,421	1,622	RLUGO-1685	0.40	53.91
527,585	942,300	1,624	RLUGO-1685	-	53.97
529,526	943,947	1,622	RLUGO-1685	1.20	54.05
529,615	944,008	1,622	RLUGO-1685	0.30	54.06
530,162	946,263	1,667	RCOL-1725	0.60	54.08
529,675	943,188	1,622	RLUGO-1685	2.70	54.09

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
530,388	948,110	1,692	RDHA-1750	-	54.13
530,460	941,998	1,602	RLUGO-1685	0.70	54.17
530,765	944,422	1,621	RLUGO-1685	1.00	54.2
531,043	947,750	1,693	RDHA-1750	-	54.2
527,452	942,327	1,624	RLUGO-1685	1.00	54.21
531,709	945,680	1,657	RCOL-1725	3.20	54.21
529,470	943,888	1,622	RLUGO-1685	1.20	54.21
529,427	943,779	1,622	RLUGO-1685	0.60	54.22
529,581	942,668	1,617	RLUGO-1685	1.60	54.22
525,730	942,684	1,702	RGA-1750	-	54.32
529,422	943,768	1,622	RLUGO-1685	-	54.36
530,367	941,892	1,602	RLUGO-1685	0.70	54.36
528,611	941,712	1,625	RLUGO-1685	1.10	54.37
528,211	944,430	1,622	RLUGO-1685	1.20	54.38
529,590	943,531	1,622	RLUGO-1685	2.10	54.39
525,728	942,654	1,702	RGA-1750	0.40	54.4
525,630	942,528	1,702	RGA-1750	-	54.61
529,105	942,008	1,623	RLUGO-1685	3.70	54.62
529,091	941,878	1,623	RLUGO-1685	-	54.65
526,031	943,299	1,703	RGA-1750	-	54.74
525,634	942,596	1,702	RGA-1750	-	54.76
526,064	943,139	1,702	RGA-1750	-	54.77
529,583	941,019	1,615	RLUGO-1685	2.30	54.85

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
530,904	946,292	1,663	RCOL-1725	1.20	54.85
529,114	944,147	1,620	RLUGO-1685	0.90	54.89
529,537	944,045	1,621	RLUGO-1685	0.20	54.9
529,453	941,547	1,618	RLUGO-1685	-	54.93
527,401	942,156	1,624	RLUGO-1685	2.40	54.94
527,955	943,638	1,621	RLUGO-1685	1.90	54.96
527,747	942,943	1,622	RLUGO-1685	0.90	54.97
525,861	942,290	1,701	RGA-1750	0.70	55.05
527,806	943,142	1,622	RLUGO-1685	0.90	55.12
529,500	943,889	1,621	RLUGO-1685	0.50	55.14
527,644	942,288	1,623	RLUGO-1685	0.30	55.14
528,795	944,273	1,620	RLUGO-1685	0.80	55.2
529,278	943,940	1,621	RLUGO-1685	0.60	55.23
529,373	943,028	1,621	RLUGO-1685	0.80	55.28
529,106	944,129	1,620	RLUGO-1685	-	55.36
528,918	944,221	1,620	RLUGO-1685	0.40	55.43
529,565	943,537	1,621	RLUGO-1685	-	55.43
529,635	943,185	1,620	RLUGO-1685	-	55.52
530,117	942,280	1,606	RLUGO-1685	0.70	55.53
529,471	941,542	1,618	RLUGO-1685	-	55.55
526,295	943,104	1,701	RGA-1750	-	55.57
529,310	943,832	1,621	RLUGO-1685	-	55.58
530,626	943,037	1,603	RLUGO-1685	2.20	55.6

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
528,050	943,989	1,620	RLUGO-1685	2.30	55.61
527,897	940,944	1,621	RLUGO-1685	0.90	55.63
528,912	944,206	1,620	RLUGO-1685	0.40	55.65
530,219	942,097	1,604	RLUGO-1685	1.50	55.66
529,233	942,335	1,621	RLUGO-1685	3.70	55.71
531,322	945,834	1,657	RCOL-1725	2.40	55.81
530,959	947,607	1,692	RDHA-1750	-	55.84
529,391	942,742	1,618	RLUGO-1685	0.70	55.9
530,357	946,222	1,665	RCOL-1725	2.20	55.95
529,468	942,911	1,620	RLUGO-1685	0.50	55.96
530,502	942,077	1,601	RLUGO-1685	0.70	55.96
529,539	943,895	1,620	RLUGO-1685	-	55.96
526,249	942,742	1,700	RGA-1750	-	56.09
529,541	943,724	1,620	RLUGO-1685	1.00	56.1
525,849	942,238	1,700	RGA-1750	-	56.19
530,934	944,355	1,619	RLUGO-1685	0.60	56.2
529,558	942,875	1,620	RLUGO-1685	-	56.2
529,556	942,955	1,620	RLUGO-1685	0.50	56.21
530,285	942,278	1,604	RLUGO-1685	0.70	56.21
527,941	943,591	1,620	RLUGO-1685	1.10	56.27
529,542	941,198	1,615	RLUGO-1685	-	56.44
528,412	943,743	1,619	RLUGO-1685	0.70	56.52
531,882	944,872	1,633	RCOL-1725	-	56.61

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
526,231	942,761	1,700	RGA-1750	-	56.62
527,546	942,515	1,621	RLUGO-1685	1.70	56.65
529,430	942,842	1,618	RLUGO-1685	0.70	56.66
530,301	946,243	1,664	RCOL-1725	-	56.73
527,607	942,378	1,621	RLUGO-1685	0.60	56.77
531,855	944,899	1,632	RCOL-1725	-	56.81
530,958	942,913	1,599	RLUGO-1685	2.30	56.83
530,135	942,327	1,605	RLUGO-1685	-	56.88
526,131	943,117	1,700	RGA-1750	-	56.88
528,780	943,828	1,619	RLUGO-1685	0.70	56.9
530,668	944,185	1,618	RLUGO-1685	0.70	56.9
528,828	943,989	1,619	RLUGO-1685	1.00	57.01
526,091	943,310	1,702	RGA-1750	-	57.12
530,636	944,110	1,618	RLUGO-1685	0.20	57.25
528,422	943,703	1,620	RLUGO-1685	0.80	57.27
528,841	943,984	1,618	RLUGO-1685	-	57.27
527,696	942,460	1,620	RLUGO-1685	0.50	57.32
530,795	942,634	1,599	RLUGO-1685	3.10	57.56
530,200	941,852	1,602	RLUGO-1685	0.70	57.56
528,515	943,723	1,620	RLUGO-1685	0.50	57.6
528,472	943,899	1,618	RLUGO-1685	1.00	57.65
528,800	942,973	1,620	RLUGO-1685	2.00	57.66
531,820	944,352	1,617	RLUGO-1685	0.80	57.68

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
530,904	947,501	1,690	RDHA-1750	-	57.75
530,810	946,057	1,659	RCOL-1725	2.50	57.77
531,627	944,402	1,617	RLUGO-1685	0.90	57.82
530,202	946,166	1,663	RCOL-1725	0.50	57.93
530,266	942,223	1,603	RLUGO-1685	0.70	57.95
527,654	940,701	1,618	RLUGO-1685	1.50	57.98
525,835	942,184	1,698	RGA-1750	0.20	57.99
530,848	947,393	1,690	RDHA-1750	-	57.99
527,350	941,590	1,621	RLUGO-1685	2.70	58.19
529,463	943,253	1,618	RLUGO-1685	0.90	58.29
529,419	942,275	1,619	RLUGO-1685	1.10	58.32
530,194	946,145	1,662	RCOL-1725	0.30	58.54
528,778	943,784	1,619	RLUGO-1685	1.40	58.57
528,997	943,781	1,618	RLUGO-1685	-	58.57
526,211	942,821	1,698	RGA-1750	-	58.6
528,550	944,102	1,617	RLUGO-1685	1.00	58.62
527,671	942,345	1,619	RLUGO-1685	0.30	58.73
531,038	944,317	1,616	RLUGO-1685	0.60	58.8
528,125	943,052	1,619	RLUGO-1685	1.20	58.87
526,123	943,316	1,700	RGA-1750	-	58.88
530,150	946,173	1,662	RCOL-1725	0.50	58.96
527,674	942,398	1,619	RLUGO-1685	-	59
530,560	942,187	1,600	RLUGO-1685	2.00	59.11

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
531,127	945,926	1,657	RCOL-1725	1.80	59.16
527,797	942,584	1,619	RLUGO-1685	0.50	59.26
530,635	944,076	1,616	RLUGO-1685	0.30	59.36
531,293	944,290	1,616	RLUGO-1685	1.50	59.4
526,210	943,094	1,697	RGA-1750	-	59.43
530,446	942,215	1,600	RLUGO-1685	-	59.57
531,138	945,956	1,656	RCOL-1725	0.90	59.59
530,797	947,267	1,688	RDHA-1750	-	59.61
530,687	944,071	1,616	RLUGO-1685	0.30	59.7
527,752	942,439	1,618	RLUGO-1685	1.90	59.84
529,021	943,837	1,616	RLUGO-1685	0.70	59.91
528,256	943,354	1,617	RLUGO-1685	0.70	60.06
530,682	944,011	1,615	RLUGO-1685	-	60.23
530,849	944,095	1,615	RLUGO-1685	0.80	60.31
530,158	941,946	1,601	RLUGO-1685	-	60.47
528,280	943,219	1,617	RLUGO-1685	0.60	60.54
531,794	944,238	1,614	RLUGO-1685	0.90	60.61
528,181	943,252	1,617	RLUGO-1685	0.70	60.62
531,150	945,405	1,652	RCOL-1725	1.50	60.67
528,238	943,316	1,616	RLUGO-1685	-	61.11
531,608	944,242	1,614	RLUGO-1685	1.60	61.31
527,460	940,507	1,614	RLUGO-1685	1.10	61.41
528,196	943,303	1,616	RLUGO-1685	-	61.41

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
530,632	943,866	1,614	RLUGO-1685	1.20	61.43
528,619	942,587	1,616	RLUGO-1685	2.40	61.45
531,124	945,415	1,651	RCOL-1725	1.50	61.56
527,756	942,300	1,616	RLUGO-1685	0.40	61.61
528,567	943,260	1,615	RLUGO-1685	2.00	61.66
526,157	943,321	1,698	RGA-1750	-	61.71
527,619	941,763	1,617	RLUGO-1685	-	61.83
528,442	942,958	1,615	RLUGO-1685	1.00	61.87
530,938	944,082	1,613	RLUGO-1685	0.80	61.93
527,965	942,522	1,616	RLUGO-1685	0.90	62.1
528,332	943,331	1,615	RLUGO-1685	0.60	62.21
527,887	942,274	1,616	RLUGO-1685	0.60	62.46
526,286	943,073	1,694	RGA-1750	0.20	62.65
527,691	941,894	1,616	RLUGO-1685	0.80	63.1
528,035	942,744	1,615	RLUGO-1685	1.30	63.12
526,184	943,330	1,697	RGA-1750	0.20	63.12
527,341	941,279	1,617	RLUGO-1685	2.20	63.24
528,289	943,001	1,614	RLUGO-1685	1.00	63.5
530,222	945,879	1,659	RCOL-1725	-	63.53
530,975	945,569	1,651	RCOL-1725	1.30	63.6
528,208	942,698	1,613	RLUGO-1685	1.70	63.73
530,241	945,925	1,658	RCOL-1725	-	63.84
527,926	942,059	1,614	RLUGO-1685	0.80	63.84

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
531,598	944,725	1,625	RCOL-1725	4.00	64.03
527,731	942,106	1,614	RLUGO-1685	0.80	64.12
530,715	947,060	1,684	RDHA-1750	-	64.15
531,237	944,049	1,611	RLUGO-1685	1.70	64.28
527,608	941,571	1,615	RLUGO-1685	2.00	64.34
530,199	945,886	1,658	RCOL-1725	-	64.41
526,554	942,989	1,692	RGA-1750	-	64.47
527,978	942,247	1,613	RLUGO-1685	0.60	64.8
530,013	946,276	1,656	RCOL-1725	0.60	64.94
529,446	946,118	1,656	RCOL-1725	1.60	64.94
530,942	945,486	1,649	RCOL-1725	1.30	65.13
530,199	945,917	1,657	RCOL-1725	-	65.18
530,199	945,918	1,657	RCOL-1725	-	65.18
530,199	945,919	1,657	RCOL-1725	-	65.18
530,812	943,817	1,610	RLUGO-1685	1.00	65.24
531,820	944,668	1,624	RCOL-1725	-	65.37
526,570	943,034	1,691	RGA-1750	0.20	65.43
527,749	941,262	1,615	RLUGO-1685	-	65.85
530,663	945,687	1,648	RCOL-1725	2.80	66.03
531,049	945,223	1,646	RCOL-1725	0.90	66.5
529,671	946,201	1,654	RCOL-1725	-	66.71
531,552	945,244	1,644	RCOL-1725	3.20	66.98
527,790	941,308	1,613	RLUGO-1685	1.90	67.22

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
531,771	944,049	1,607	RLUGO-1685	0.50	67.52
527,645	941,144	1,613	RLUGO-1685	1.90	67.72
531,858	943,960	1,607	RLUGO-1685	-	67.85
531,572	944,013	1,607	RLUGO-1685	0.70	67.99
526,254	943,338	1,693	RGA-1750	-	68.08
526,277	943,341	1,693	RGA-1750	-	68.21
527,589	941,192	1,612	RLUGO-1685	-	68.24
531,580	944,069	1,607	RLUGO-1685	0.70	68.27
527,565	941,199	1,612	RLUGO-1685	-	68.4
527,459	941,253	1,612	RLUGO-1685	-	68.51
531,898	943,938	1,606	RLUGO-1685	-	68.76
531,979	943,848	1,606	RLUGO-1685	1.00	68.91
531,761	943,988	1,606	RLUGO-1685	0.50	68.91
526,402	943,359	1,694	RGA-1750	-	69.72
526,410	943,360	1,693	RGA-1750	-	70.29
531,790	939,373	1,645	R09EBO-1715	-	70.45
526,375	943,353	1,692	RGA-1750	-	70.84
526,397	943,358	1,692	RGA-1750	-	70.94
526,313	943,344	1,690	RGA-1750	-	71.82
526,446	943,367	1,692	RGA-1750	0.40	71.88
530,775	945,088	1,642	RCOL-1725	1.30	71.89
530,617	946,812	1,676	RDHA-1750	-	71.96
530,967	945,012	1,640	RCOL-1725	1.80	72.49

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
526,356	943,351	1,689	RGA-1750	-	73.32
526,530	943,349	1,689	RGA-1750	-	76.18
530,506	946,530	1,670	RDHA-1750	-	78.53
531,371	939,217	1,637	R09EBO-1715	-	79.03
526,587	943,348	1,687	RGA-1750	-	79.08
530,409	946,286	1,666	RDHA-1750	-	82.84
531,246	939,462	1,632	R09EBO-1715	-	83.36
526,631	943,359	1,683	RGA-1750	-	83.69
531,062	939,143	1,643	R09EBO-1715	-	85.68
530,343	946,117	1,661	RDHA-1750	-	88.06
530,286	945,970	1,659	RDHA-1750	-	89.52
530,193	945,886	1,658	RDHA-1750	-	91.5
531,075	939,887	1,624	R09EBO-1715	-	91.7
530,193	945,919	1,657	RDHA-1750	-	91.97
530,248	945,872	1,656	RDHA-1750	-	92.53
531,095	939,270	1,638	R09EBO-1715	-	92.74
526,694	943,365	1,672	RGA-1750	0.20	95.83
531,427	940,095	1,620	R09EBO-1715	-	96.1
530,910	940,290	1,616	R09EBO-1715	-	99.49
531,240	940,457	1,614	R09EBO-1715	-	101.78
526,749	943,373	1,657	RGA-1750	-	111.52
526,776	943,375	1,647	RGA-1750	0.40	122.16
526,897	943,385	1,640	RGA-1750	1.80	131.38

X (m)	Y (m)	Elevation (m)	Zone	Base Flow (l/s)	Pressure (m H2O)
526,892	943,400	1,640	RGA-1750	-	131.78

Appendix 3: Pipe Report(PDD)

Label	Length (m)	Velocity (m/s)	Diameter (mm)	Material	Discharge (l/s)	From Node	To Node
PE-02	874	1.17	40	uPVC	1.5	N3C	N3G
PE-10	52	0.98	50	uPVC	1.9	N3H	N3H1
PE-57	301	0.51	50	uPVC	1	N9B	N18C
PE-07	87	0.96	50	uPVC	-1.9	N3I	N3E
PE-276	179	2.07	50	uPVC	4.1	N47A1	N51B
PE-12	87	0.98	50	uPVC	1.9	N3H2	N3H3
PE-69	361	0.56	50	uPVC	1.1	N21	N18B
PE-183	290	0.13	50	uPVC	-0.3	N81D	N81D1
PE-74	148	0.39	50	uPVC	-0.8	N20A	N20B
PE-352	68	0.12	50	uPVC	-0.2	N28A	N28AA
PE-405	248	0.04	50	uPVC	0.1	N59A	N59
PE-412	192	0.21	50	uPVC	0.4	N24C	N24D
PE-237	494	0.22	50	uPVC	0.4	N46A1	N44A1
PE-254	193	0.43	50	uPVC	-0.9	N45'	N45'A
EG-56	142	0.25	50	uPVC	0.5	NG-48	NG-47
EG-90	55	0.25	50	uPVC	0.5	NG-47	NG-40
PE-500	209	0.63	50	uPVC	1.2	N63B'2	N63B'1
EG-54	48	0.11	50	DI	0.2	NG-38	NG-46
EG-49	281	0.11	50	uPVC	0.2	NG-16	NG-38
EG-55	32	0.25	50	uPVC	0.5	NG-16	NG-48
PE-499	42	0.63	50	uPVC	1.2	N67A	N63B'2
ED-54	150	0	50	GI	0	ND-45	ND-46
PE-451	206	0.35	50	uPVC	0.7	N111C	N78
PE-501	36	0.32	50	uPVC	0.6	N63B'1	N63B'
ED-46	271	0	50	GI	0	ND-42	ND-44
ED-55	706	0	50	GI	0	ND-46	ND-41
PE-355	135	0.18	50	uPVC	-0.4	N28C	N28A'
PE-11	85	0.98	50	uPVC	1.9	N3H1	N3H2
PE-402	273	0.07	50	uPVC	0.1	N22B	N57A
PE-177	141	0.28	50	uPVC	0.6	N81E	N81C
PE-08	462	1.03	50	uPVC	-2	N3J	N3J1
PE-38	164	0.61	50	uPVC	1.2	N5A	N7C
PE-361	11	0.23	50	uPVC	0.5	N54E2	N54E1

PE-411	62	0.39	50	uPVC	-0.8	N24D	N24A1
PE-13	89	0.98	50	uPVC	1.9	N3H3	N3I
PE-333	213	0.11	50	uPVC	0.2	N64B1	N64A
PE-337	515	0.06	50	uPVC	-0.1	N65A	N63A
PE-318	150	0.07	50	uPVC	-0.1	N52'	N64D
PE-06	276	1.15	50	uPVC	-2.3	N3J	N3I
PE-362	12	0.23	50	uPVC	0.5	N54E1	N54E
PE-58	310	0.67	50	uPVC	-1.3	N18C	N18A
PE-223	331	0.23	50	uPVC	0.4	N43B	N43A
PE-353	136	0.09	50	uPVC	0.2	N28A'	N28A
PE-03	434	1.15	50	uPVC	-2.3	N3G	N3E
PE-432	255	0.2	50	uPVC	0.4	N63B	N63B1
PE-363	133	0.09	50	uPVC	0.2	N54E	N54
PE-255	314	0.87	50	uPVC	-1.7	N45'A	N45
PE-04	861	1.2	50	uPVC	-2.4	N3E	N3D
PE-05	293	0.62	50	uPVC	-1.2	N3G	N3J
PE-360	119	0.23	50	uPVC	0.5	N55A	N54E2
PE-184	135	0.35	50	uPVC	0.7	N81C	N81D
EG-88	223	0.25	50	uPVC	0.5	NG-50	NG-39
ED-53	694	0	65	GI	0	ND-31	ND-46
ED-51	746	0	65	GI	0	ND-34	ND-45
PE-480	625	0.19	80	uPVC	0.9	N105A3	N105A4
PE-414	199	0.23	80	uPVC	-1.1	N24E2	N24B
PB-09	436	0	80	uPVC	0	BA-04	BA-01
PE-14	220	1.71	80	uPVC	-8.6	N3H	N3F
PE-216	333	0.25	80	uPVC	-1.3	N42	N36
PE-174	26	0.19	80	uPVC	0.9	N81C3	N81C2
PE-272	104	0.53	80	uPVC	-2.7	N47C	N47B
PE-481	103	0.32	80	uPVC	-1.6	N105A4	N105D
PE-438	180	1.43	80	uPVC	7.2	N71C	N71B
PE-117	122	0.5	80	uPVC	2.5	N11A1	N11A2
PE-09	290	1.01	80	uPVC	-5.1	N3J1	N3H
PE-278	317	3.03	80	uPVC	15.2	N51B	N50
PE-173	459	0.45	80	uPVC	2.2	N81A1	N81C3
PE-30	109	1.64	80	uPVC	8.3	N7A	N7A1
PE-478	69	1.01	80	uPVC	5.1	N105A1	N105A2
PE-371	273	0.08	80	uPVC	-0.4	N54C	N54D
PE-372	262	0.18	80	uPVC	0.9	N56A	N54C
PE-15	403	1.62	80	uPVC	8.1	N3F	N3E
PE-207	97	0.25	80	uPVC	-1.3	N39B5	N39A7
ED-44	183	0	80	uPVC	0	ND-35	ND-42

PE-182	274	0.28	80	uPVC	-1.4	N81D1	N81F
PE-300	215	0.42	80	uPVC	-2.1	N52C	N53A1
PE-18	477	2.32	80	uPVC	-11.6	N3B	N3B1
PE-260	325	0.3	80	uPVC	1.5	N44B2	N44B3
PE-217	179	0.35	80	uPVC	1.8	N36	N36A
PE-75	105	0.55	80	uPVC	2.8	N20A	N21B
EG-67	68	0.17	80	uPVC	0.8	NG-28	NG-29
PE-498	48	0.22	80	uPVC	1.1	N67	N67A
PE-298	213	0.36	80	uPVC	-1.8	N52A	N32C
PE-258	138	0.57	80	uPVC	2.8	N44A	N44B1
PE-323	208	0.04	80	uPVC	0.2	N64D	N64E
PE-50	248	0.1	80	uPVC	-0.5	N6B	N6B1
EG-66	110	0.17	80	uPVC	0.8	NG-27	NG-28
PE-471	273	0.77	80	uPVC	3.9	N106	N106B
PE-19	188	1.02	80	uPVC	5.1	N3B1	N3B2
EG-71	57	0.12	80	uPVC	0.6	NG-32	NG-33
PE-175	116	0.19	80	uPVC	0.9	N81C2	N81C1
PE-110	197	0.19	80	uPVC	1	N14B	N14B1
ED-52	647	0	80	uPVC	0	ND-33	ND-45
PE-259	85	0.57	80	uPVC	2.8	N44B1	N44B2
EG-70	24	0.12	80	uPVC	0.6	NG-31	NG-32
PE-439	298	1.43	80	uPVC	7.2	N109	N71C
PE-209	66	0.23	80	uPVC	1.1	N39B6	N38A1
EG-76	9	0.09	80	uPVC	0.4	NG-90	NG-52
PE-53	139	1.09	80	uPVC	-5.5	N6B3	N6B4
PE-51	182	0.46	80	uPVC	-2.3	N6B1	N6B2
PE-299	208	0.17	80	uPVC	-0.8	N52A	N52C
PE-261	326	0.16	80	uPVC	-0.8	N44B3	N44B4
PE-288	300	0.12	80	uPVC	-0.6	N47A	N32A
EG-75	56	0.13	80	uPVC	0.7	NG-36	NG-90
PE-204	61	0.05	80	uPVC	0.3	N39B2	N39B3
PE-202	196	0.31	80	uPVC	-1.5	N39A7	N39A4
PE-76	163	0.43	80	uPVC	2.2	N21B	N21C
ED-45	108	0	80	uPVC	0	ND-42	ND-43
PE-203	135	0.2	80	uPVC	1	N39B	N39B2
EG-78	801	0.17	80	uPVC	0.9	NG-27	NG-41
PE-205	80	0.15	80	uPVC	0.7	N39B2	N39B4
PE-479	49	0.19	80	uPVC	0.9	N105A2	N105A3
PE-334	212	0.04	80	uPVC	0.2	N64A	N65B
EG-68	59	0.17	80	uPVC	0.8	NG-29	NG-30
PE-474	449	0.26	80	uPVC	1.3	N105C	N105C'

PE-454	398	0.55	80	uPVC	2.8	N102	N111
PE-477	230	1.01	80	uPVC	5.1	N105A	N105A1
PE-262	344	0.63	80	uPVC	-3.2	N44B4	N44B
PE-105	40	0.4	80	uPVC	2	N16A1	N16A
PE-473	691	0.61	80	uPVC	-3	N105C'	N106B
PE-77	190	0.22	80	uPVC	1.1	N21C	N21D
PE-181	259	0.25	80	uPVC	-1.2	N81F	N81E
EG-69	57	0.17	80	uPVC	0.8	NG-30	NG-31
PE-111	80	0.1	80	uPVC	0.5	N14B1	N14B2
PE-206	72	0.03	80	uPVC	0.1	N39B4	N39B5
PE-201	133	0.03	80	uPVC	0.1	N37	N39A7
PE-373	217	0.25	80	uPVC	1.2	N54C	N54B1
PE-112	97	0.1	80	uPVC	0.5	N14B2	N14B3
PE-52	191	0.46	80	uPVC	-2.3	N6B2	N6B3
PB-03	371	0	80	uPVC	0	BA-01	BA-02
PE-54	285	1.44	80	uPVC	-7.3	N6B4	N9B1
PE-285	16	0.76	80	uPVC	3.8	N53A	N53A1
PE-78	263	0.37	80	uPVC	-1.9	N20B	N22E
PE-367	143	0.33	80	uPVC	1.7	N56	N54D
PE-391	82	0.14	80	uPVC	-0.7	N27C	N22
PE-104	185	0.4	80	uPVC	2	N31B	N16A1
PE-375	299	0.03	80	uPVC	0.2	N56B1	N55A'
PE-68	369	0.39	80	uPVC	-2	N21	N17A
PE-122	486	0.79	80	uPVC	-4	N10	N16A
PE-417	117	0.06	80	uPVC	-0.3	N24E1	N24E2
PE-413	191	0.13	80	uPVC	0.6	N24D	N24E1
PE-109	242	0.25	80	uPVC	-1.2	N14B	N31B
EG-73	97	0.12	80	uPVC	0.6	NG-34	NG-35
EG-77	133	0.14	80	uPVC	-0.7	NG-35	NG-50
PE-208	53	0.23	80	uPVC	1.1	N39B5	N39B6
EG-72	91	0.12	80	uPVC	0.6	NG-33	NG-34
PB-04	407	0	80	uPVC	0	BA-03	BA-02
PE-180	343	0.33	80	uPVC	1.6	N81B1	N81F
EG-74	53	0.13	80	uPVC	0.7	NG-35	NG-36
PE-428	380	0.11	80	uPVC	0.5	N68C1	N62
PE-407	247	0.06	80	uPVC	-0.3	N59A	N24
PE-22	541	3.11	80	uPVC	-15.6	N6C	N6A
PE-385	261	0.13	80	uPVC	0.7	N55A'	N55B
PE-73	296	0.62	80	uPVC	3.1	N20	N20A
PE-286	134	0.26	80	uPVC	1.3	N53A1	N53B
PE-178	323	0.5	80	uPVC	-2.5	N81E	N81B

PE-179	237	0.5	80	uPVC	2.5	N81B	N81B1
PE-312	206	0.09	80	uPVC	-0.4	N52'	N51A
PE-172	162	0.51	80	uPVC	2.5	N81A	N81A1
PE-116	152	0.55	80	uPVC	-2.7	N11A1	N14B
PE-55	30	1.44	80	uPVC	-7.3	N9B1	N9B
PE-118	108	0.36	80	uPVC	1.8	N11A2	N11
PE-31	356	1.35	80	uPVC	6.8	N7A1	N6B
PE-176	100	0.11	80	uPVC	0.6	N81C1	N81C
PE-115	108	0.05	80	uPVC	-0.2	N11A	N11A1
PE-23	153	1.27	100	uPVC	-10	N6A	N6A1
PE-24	103	1.48	100	uPVC	-11.6	N6A1	N6A2
PE-20	196	2.14	100	uPVC	-16.8	N3B1	N3
PE-108	226	0.41	100	uPVC	3.2	N14A	N14B
PE-332	161	0.15	100	uPVC	1.2	N64B1	N63A
PE-306	88	0.06	100	uPVC	-0.5	N47A3	N47A1
PE-327	151	0.14	100	uPVC	1.1	N47A1	N47A2
PE-328	215	0.08	100	uPVC	0.7	N64E	N64A
PE-26	65	1.48	100	uPVC	-11.6	N6A3	N6A4
PE-01	312	1.34	100	uPVC	10.5	N3D	N3C
PE-170	100	1.1	100	uPVC	8.6	N81	N81A
PE-292	224	0.03	100	uPVC	-0.2	N29	N32C
PE-322	214	0.14	100	uPVC	1.1	N64B1	N64D
P-811	232	0.66	100	uPVC	5.2	N3B	ILEBO-23
PE-319	92	0.11	100	uPVC	-0.9	N64A1	N64A2
PE-329	215	0.09	100	uPVC	0.7	N65C	N65B
PE-59	355	0.6	100	uPVC	4.7	N18A	N19
PE-320	271	0.19	100	uPVC	-1.5	N64A2	N64B
PB-05	275	0	100	uPVC	0	BA-05	BA-10
PE-27	46	1.48	100	uPVC	-11.6	N6A4	N6
PB-06	458	0	100	uPVC	0	BA-10	BA-04
PE-70	383	0.74	100	uPVC	-5.8	N18B	N18A
PE-171	100	0.73	100	uPVC	5.7	N81A	N81B
PE-67	163	0.14	100	uPVC	1.1	N17B	N21
PE1-450	226	0.14	100	uPVC	1.1	IAU-01	N78
PE-279	519	0.88	100	uPVC	6.9	N50	N48
PE-415	161	0.26	100	uPVC	-2	N24B	N24E
PE-79	417	0.37	100	uPVC	-2.9	N22E	N18B
PE-29	90	0.04	100	uPVC	0.3	N7D	N7A
PE-317	233	0.12	100	uPVC	-0.9	N64A1	N52'
PE-331	213	0.1	100	uPVC	0.8	N47A2	N65
PE-277	603	1.67	100	uPVC	-13.1	N51B	N47C

PE-325	216	0.03	100	uPVC	0.2	N64E	N65C
PE-25	230	1.48	100	uPVC	-11.6	N6A2	N6A3
PB-10	808	0	100	uPVC	0	BA-03	BA-06
PE-336	153	0.1	100	uPVC	0.8	N65	N65A
PE-421	195	0.32	100	uPVC	-2.5	N61	N56A1
PE-66	374	0.39	100	uPVC	3.1	N17	N17B
PE-39	261	0.75	100	uPVC	5.9	N7C	N7D
PE-72	384	0.47	100	uPVC	-3.7	N20	N19
PE-424	197	0.26	100	uPVC	-2.1	N61A	N54D'
PE-305	82	0.11	100	uPVC	0.9	N47A4	N47A3
PE-291	113	0.58	100	uPVC	4.5	N29	N29A1
PB-13	447	0	100	uPVC	0	BA-05	BA-06
PE-44	135	0.79	100	uPVC	6.2	N7B	N7C
PE-335	89	0.06	100	uPVC	0.4	N65B	N65
PE-71	311	0.21	100	uPVC	1.6	N18B	N20
PE-387	263	0.15	100	uPVC	-1.2	N58	N57
PE-21	378	2.76	100	uPVC	21.7	N3	N3D
PE-96	126	0.32	100	uPVC	2.5	N30A6	N30A7
PE-330	88	0.01	100	uPVC	0.1	N65C	N47A2
P-812	392	1.38	100	uPVC	10.8	N42	ILWBO-01
PE-314	136	0.14	100	uPVC	-1.1	N51A	N47A4
PE-33	172	0.95	100	uPVC	-7.5	N6	N4
PE-301	153	0.16	100	uPVC	1.3	N52C	N52B'
PE-430	101	0.27	100	uPVC	-2.1	N63B	N63A1
PE-17	126	0.58	100	uPVC	-4.6	N6C	N3B
PE-326	149	0.13	100	uPVC	-1.1	N65C	N47A3
PE-294	209	0.37	100	uPVC	-2.9	N53'	N53A
PE-40	125	1.1	100	uPVC	-8.7	N7A	N7
EG-08	86	0.98	100	DI	7.7	NG-60	NG-61
PE-442	464	0.08	100	uPVC	-0.7	N71'	N109B
EG-09	37	0.92	100	DI	7.2	NG-61	NG-62
PE-516	178	0.43	100	uPVC	3.4	N69A	N69A1
EG-07	57	0.98	100	DI	7.7	NG-59	NG-60
PE-490	52	0.11	100	uPVC	0.9	N103C1	N103C2
EG-11	5	0.92	100	DI	7.2	NG-04	NG-05
EG-10	8	0.92	100	DI	7.2	NG-62	NG-04
EG-79	79	0.23	100	uPVC	1.8	NG-27	NG-02
EG-13	18	0.92	100	DI	7.2	NG-63	NG-64
EG-12	23	0.92	100	DI	7.2	NG-05	NG-63
EG-06	46	0.98	100	DI	7.7	NG-58	NG-59
PE-476	338	0.88	100	uPVC	-6.9	N105C1	N105A

EG-80	57	0.2	100	uPVC	1.6	NG-02	NG-49
PE-504	134	0.13	100	uPVC	-1	N68A1	N68A2
PE-505	190	0.3	100	uPVC	-2.4	N68A2	N68A3
ED-47	378	0.01	100	uPVC	0.1	ND-36	ND-47
ED-49	867	0	100	uPVC	0	ND-47	ND-40
EG-05	63	0.98	100	DI	7.7	NG-57	NG-58
EG-04	56	1	100	DI	7.9	NG-56	NG-57
EG-03	27	1	100	DI	7.9	NG-55	NG-56
PE-453	333	0.01	100	uPVC	-0.1	N111	N111A
PE-452	432	0.26	100	uPVC	2	N111A'	N111C
EG-18	29	0.89	100	DI	7	NG-68	NG-69
EG-23	38	0.89	100	DI	7	NG-73	NG-74
EG-19	34	0.89	100	DI	7	NG-69	NG-70
PE-485	254	0.19	100	uPVC	1.5	N103A	N103B
EG-20	32	0.89	100	DI	7	NG-70	NG-71
EG-02	16	1.29	100	DI	10.1	NG-54	NG-53
EG-86	4	0.64	100	DI	5.1	PMAG-2	NG-54
P-1324	45	0.89	100	DI	7	N45	FCV-BAG
EG-85	4	0.64	100	DI	5.1	RAG-1640	PMAG-2
EG-83	3	0.64	100	DI	5.1	RAG-1640	PMAG-1
EG-84	4	0.64	100	DI	5.1	PMAG-1	NG-54
PE-502	70	0.13	100	uPVC	-1	N67A	N68
PE-503	134	0.13	100	uPVC	-1	N68	N68A1
EG-16	23	0.92	100	DI	7.2	NG-66	NG-67
PE-448	196	0.61	100	uPVC	-4.8	N70'	N111A'
EG-14	43	0.92	100	DI	7.2	NG-64	NG-65
EG-17	70	0.92	100	DI	7.2	NG-67	NG-68
EG-15	37	0.92	100	DI	7.2	NG-65	NG-66
EG-22	47	0.89	100	DI	7	NG-72	NG-73
EG-21	61	0.89	100	DI	7	NG-71	NG-72
PE-472	483	0.35	100	uPVC	-2.8	N106B	N105A
PE-491	22	0.04	100	uPVC	0.3	N103C2	N103D
PE-517	194	0.4	100	uPVC	3.2	N69A1	N69A2
PE-449	28	0.16	100	uPVC	1.3	N70'	N70
EG-53	27	0.24	100	uPVC	1.9	NG-18	NG-19
EG-89	95	0.24	100	uPVC	1.9	NG-19	NG-37
PE-450	206	0.26	100	uPVC	-2	IAU-01	N70'
PE-290	130	0.6	100	uPVC	4.7	N32B	N29
PE-293	20	0.37	100	uPVC	-2.9	N32C	N53'
ED-48	276	0	100	uPVC	0	ND-47	ND-38
ED-43	739	0	100	uPVC	0	ND-39	ND-37

PE-443	433	0.49	100	uPVC	3.8	N70	N109B
PE-489	91	0.18	100	uPVC	1.4	N103C	N103C1
PE-506	109	0.35	100	uPVC	-2.8	N68A3	N68C
PE-475	357	0.54	100	uPVC	-4.2	N105C	N105C1
PE-482	237	0.38	100	uPVC	-3	N105D	N105C
EG-52	34	0.24	100	uPVC	1.9	NG-45	NG-18
ED-50	429	0.01	100	uPVC	0.1	ND-47	ND-32
PE-429	98	0.17	100	uPVC	-1.3	N68C1	N63B
EG-81	166	0.2	100	uPVC	1.6	NG-49	NG-50
EG-51	30	0.24	100	uPVC	1.9	NG-17	NG-45
EG-01	121	1.06	100	DI	-8.3	NG-55	NG-53
EG-50	263	0.24	100	uPVC	1.9	NG-16	NG-17
PE-518	98	0.35	100	uPVC	2.7	N69A2	N69
PE-515	135	0.46	100	uPVC	3.6	N68D	N69A
EG-28	8	0.05	150	DI	-0.8	NG-06	NG-78
PE-60	323	0.07	150	uPVC	-1.2	N19	N9B
PE-99	219	0.42	150	uPVC	7.4	N31C	N31D1
PE-213	180	0.16	150	uPVC	-2.8	N38A3	N38B
EG-27	21	0.05	150	DI	-0.8	NG-77	NG-06
EG-25	20	0.05	150	uPVC	-0.8	NG-75	NG-76
EG-31	41	0.05	150	DI	-0.8	NG-79	NG-80
EG-61	65	0.22	150	uPVC	4	NG-22	NG-23
EG-24	4	0.4	150	uPVC	7	NG-74	NG-75
EG-26	26	0.05	150	DI	-0.8	NG-76	NG-77
EG-29	5	0.05	150	DI	-0.8	NG-78	NG-03
EG-30	18	0.05	150	DI	-0.8	NG-03	NG-79
EG-33	50	0.05	150	DI	-0.8	NG-81	NG-82
PE-153	98	0.23	150	uPVC	4.1	N15D1	N15D
EG-62	152	0.22	150	uPVC	4	NG-23	NG-24
EG-39	24	0.05	150	DI	-0.8	NG-88	NG-89
EG-38	34	0.05	150	DI	-0.8	NG-87	NG-88
PE-426	215	0.21	150	uPVC	3.7	N62	N61A
EG-82	37	0.05	150	DI	-0.8	NG-85	NG-86
EG-37	41	0.05	150	DI	-0.8	NG-86	NG-87
PE-242	61	0.19	150	uPVC	3.3	N43A3	N43A4
EG-32	64	0.05	150	DI	-0.8	NG-80	NG-81
PE-230	41	0.18	150	uPVC	3.1	N43B6	N35
EG-35	38	0.05	150	DI	-0.8	NG-83	NG-84
EG-34	30	0.05	150	DI	-0.8	NG-82	NG-83
EG-36	34	0.05	150	DI	-0.8	NG-84	NG-85
PE-148	59	0.41	150	uPVC	7.2	N15F	N15F1

PE-370	258	0.19	150	uPVC	3.3	N56B1	N56A
PE-253	249	0.51	150	uPVC	-9.1	N31	N33
PE-243	333	0.46	150	uPVC	8	N43A4	N43A5
EG-46	70	0.16	150	uPVC	2.8	NG-13	NG-14
PE-152	80	0.23	150	uPVC	4.1	N15D2	N15D1
PE-100	26	0.42	150	uPVC	7.4	N31D1	N31D
EG-47	82	0.16	150	uPVC	2.8	NG-14	NG-15
PE-103	230	0.24	150	uPVC	4.2	N31A	N31B
EG-48	79	0.16	150	uPVC	2.8	NG-15	NG-16
EG-65	30	0.22	150	uPVC	4	NG-26	NG-27
PE-338	144	0.31	150	uPVC	-5.5	N64B	N54A
EG-64	116	0.22	150	uPVC	4	NG-25	NG-26
PE-56	505	0.71	150	uPVC	-12.6	N9B	N7
PE-404	509	0.07	150	uPVC	1.2	N58	N59
PE-313	242	0.09	150	uPVC	-1.7	N51A	N52B'
EG-45	73	0.16	150	uPVC	2.8	NG-12	NG-13
PE-274	284	0.24	150	uPVC	-4.3	N46B1	N46B
EG-57	54	0.24	150	uPVC	4.2	NG-09	NG-20
PE-34	223	2.93	150	uPVC	51.8	N4	N4A
PE-212	151	0.13	150	uPVC	-2.3	N38A2	N38A3
PE-236	96	0.02	150	uPVC	0.3	N46A2	N46A1
EG-60	81	0.22	150	uPVC	4	NG-21	NG-22
EG-58	27	0.24	150	uPVC	4.2	NG-20	NG-01
EG-59	57	0.22	150	uPVC	4	NG-01	NG-21
PE-324	148	0.1	150	uPVC	-1.7	N64E	N51A
PE-287	166	0.37	150	uPVC	-6.5	N53B	N47
EG-44	45	0.16	150	uPVC	2.8	NG-11	NG-12
PE-374	294	0.08	150	uPVC	1.5	N56A	N55B
PE-257	329	0.16	150	uPVC	-2.8	N45A'	N44A
EG-42	25	0.16	150	uPVC	2.8	NG-09	NG-10
PE-32	56	0.41	150	uPVC	7.3	N6B	N6A
EG-43	63	0.16	150	uPVC	2.8	NG-10	NG-11
PE-401	122	0.06	150	uPVC	1	N25A2	N25A
PE-244	87	0.41	150	uPVC	7.2	N43A5	N45A'
PE-151	232	0.3	150	uPVC	5.3	N15E	N15D2
PE-436	214	0.23	150	uPVC	4	N71BC	N71D
PE-511	112	0.25	150	uPVC	4.5	N67A4	N67A3
PE-369	123	0.24	150	uPVC	4.2	N56B	N56B1
PE-513	108	0.25	150	uPVC	4.5	N67A2	N67A1
PE-232	53	0.18	150	uPVC	3.1	N43B4	N43B5
PE-494	240	0.09	150	uPVC	1.6	N107'	N108A

PE-239	387	0.06	150	uPVC	1	N35	N46A1
PE-496	135	0.04	150	uPVC	-0.8	N67E	N67E1
PE-365	166	0.21	150	uPVC	3.7	N54E	N54D
PE-386	265	0.07	150	uPVC	1.3	N55B	N58
PE-497	384	0.14	150	uPVC	-2.4	N67E1	N67
PE-420	540	0.1	150	uPVC	-1.8	N58A2	N61
PE-447	89	0.46	150	uPVC	8.1	N111A	N111A'
PE-302	132	0.22	150	uPVC	-3.9	N52B'	N52D
PE-493	351	0.09	150	uPVC	1.6	N107	N107'
PE-514	46	0.25	150	uPVC	4.5	N67A1	N67
PE-310	207	0.17	150	uPVC	-3	N52B	N52B'
PE-368	127	0.25	150	uPVC	4.4	N54D	N54F
EG-63	48	0.22	150	uPVC	4	NG-24	NG-25
PE-271	182	0.62	150	uPVC	11	N47	N47C
PE-235	270	0.26	150	uPVC	-4.6	N33	N46A2
PE-495	172	0.04	150	uPVC	-0.8	N67C	N67E
PE-61	364	0.79	150	uPVC	-14	N18A	N18
PE-400	45	0.06	150	uPVC	1	N25A1	N25A2
PE-275	603	0.38	150	uPVC	6.7	N47	N47A1
PE-273	470	0.18	150	uPVC	-3.2	N47B	N46B1
PE-149	142	0.41	150	uPVC	7.2	N15F1	N15F2
PE-445	215	1.07	150	uPVC	18.9	N102A	N71
PE-263	589	0.4	150	uPVC	-7	N44A	N44
PE-437	65	0.32	150	uPVC	5.6	N71B	N71BC
PE-304	240	0.13	150	uPVC	2.3	N52D	N47A4
PE-459	343	0.63	150	uPVC	11.2	N102	N102A
PE-434	214	0.23	150	uPVC	4	N71E	N74
PE-441	417	0.71	150	uPVC	12.5	N71	N71'
PE-231	44	0.18	150	uPVC	3.1	N43B5	N43B6
PE-16	190	1.03	150	uPVC	-18.3	N3F	N6C
PE-510	71	0.25	150	uPVC	4.5	N68D	N67A4
PE-241	211	0.23	150	uPVC	4	N43A2	N43A3
PE-423	266	0.29	150	uPVC	-5.2	N61	N61A
PE-28	141	0.27	150	uPVC	-4.8	N6	N7D
PB-23	873	0.94	150	DI	16.6	BA-08	BA-09
PB-20	119	0.94	150	DI	16.6	BO-06	RBOK-1715
PB-26	110	0.94	150	DI	16.6	PMBK-1	BO-05
PB-25	2	0.94	150	DI	16.6	RBOK-1630	PMBK-1
PE-418	532	0.26	150	uPVC	-4.5	N58A1	N56A1
PE-256	121	0.54	150	uPVC	-9.6	N45	N45A'

PB-18	403	0.84	150	uPVC	14.8	J-1618	BO-08
PB-24	131	0.94	150	DI	16.6	BO-05	BA-08
P-1847	126	1.23	150	uPVC	21.7	NNL-03	J-1618
PE-211	60	0.02	150	uPVC	-0.4	N38A1	N38A2
PB-15	458	0.84	150	uPVC	14.8	BO-04	BO-01
PE-65	205	0.32	150	uPVC	5.6	N17A	N17
PE-399	100	0.06	150	uPVC	1	N24A1	N25A1
PE-36	715	0.16	150	uPVC	2.9	N4A	N4B
PE-280	85	0.35	150	uPVC	6.3	N48	N48B
EG-92	32	0.05	150	DI	0.8	RGA-1750	NG-89
PB-08	3	0.84	150	DI	14.8	FCV-BOK	RBOK-1630
PE-35	682	2.47	150	uPVC	43.6	N4A	N3
P-1844	89	1.23	150	uPVC	21.7	NN-02	J-1616
P-1846	284	1.38	150	uPVC	24.4	ILEBO-01	NN-02
PE-210	159	0.06	150	uPVC	-1	N38A	N38A1
PB-07	208	0.84	150	uPVC	14.8	BO-01	FCV-BOK
PB-19	327	0.84	150	uPVC	14.8	BO-08	BO-09
PE-150	154	0.37	150	uPVC	6.6	N15F2	N15E
PE-435	38	0.23	150	uPVC	4	N71D	N71E
PE-512	125	0.25	150	uPVC	4.5	N67A3	N67A2
PE-433	229	0.23	150	uPVC	4	N74	N77
PE-106	354	0.27	150	uPVC	-4.7	N16A	N31D
PE-444	462	0.23	150	uPVC	4	N71	N70
PE-358	315	0.23	150	uPVC	4	N28C	N54E
PE-247	279	0.39	150	uPVC	-6.9	N43A7	N43
PE-446	388	0.54	150	uPVC	-9.6	N111A	N102A
PE-240	404	0.26	150	uPVC	4.7	N43A1	N43A2
PE-483	282	0.97	150	uPVC	-17.1	N105A	N105
PB-14	434	0.84	150	uPVC	14.8	BO-09	BO-04
PE-246	173	0.35	150	uPVC	-6.1	N43A6	N43A7
P-1843	675	1.23	150	uPVC	21.7	J-1616	NNL-03
PB-21	261	0.94	150	DI	16.6	BO-07	BO-06
P-1819	270	0.32	150	uPVC	5.6	N50	ILWA-01
PB-22	182	0.94	150	DI	16.6	BA-09	BO-07
PE-303	365	0.4	150	uPVC	-7.1	N52D	N53B
PE-245	180	0.31	150	uPVC	-5.5	N43A4	N43A6
ED-42	733	0	150	uPVC	0	ND-36	ND-39
P-1822	306	0.32	150	uPVC	-5.6	ILWA-02	N48B
PE-440	404	0.57	150	uPVC	10	N71'	N109
PE-356	131	0.14	200	uPVC	4.4	N29B	N28C
PE-315	239	0.17	200	uPVC	5.2	N29B'	N54A1

PE-41	118	0.74	200	uPVC	-23.2	N7	N7AB1
PE-219	427	0.07	200	uPVC	-2.1	N36A1	N36A2
PE-47	158	1.01	200	uPVC	-31.6	N7B2	N8
PE-388	259	0.11	200	uPVC	-3.5	N57	N55A'
PE-220	289	0.13	200	uPVC	-4.1	N36A2	N14
PE-45	159	0.98	200	uPVC	-30.9	N7B	N7B1
PE-89	240	0.25	200	uPVC	-7.9	N22A5	N28B1
PE-43	57	0.76	200	uPVC	-23.9	N7AB	N7B
PE-396	301	0.2	200	uPVC	6.4	N22C	N24
PE-419	191	0.14	200	uPVC	4.5	N58A1	N58A2
PE-384	259	0.16	200	uPVC	5	N27B3	N55A'
PE-425	215	0.34	200	uPVC	-10.8	N54D'	N54B1'
PE-85	312	0.19	200	uPVC	-6.1	N22A1	N22A2
PE-397	337	0.14	200	uPVC	4.4	N24	N24A
PE-406	256	0.15	200	uPVC	4.6	N57A'	N59A
PE-383	24	0.33	200	uPVC	10.5	N27B	N27B3
PE-284	232	0.23	200	uPVC	7.1	N32A	N53A
PE-431	376	0.09	200	uPVC	-2.8	N63A1	N54B1'
PE-416	111	0.17	200	uPVC	5.2	N57A	N57A'
PE-366	15	0.14	200	uPVC	4.5	N56	N56B
PE-229	79	0.05	200	uPVC	1.4	N35	N35A
PE-225	327	0.07	200	uPVC	-2.3	N43B2	N34
PE-309	153	0.04	200	uPVC	-1.3	N52B	N52A
PE-408	318	0.11	200	uPVC	3.4	N59A	N24E
PE-389	256	0.14	200	uPVC	-4.4	N57	N27C
PE-376	281	0.13	200	uPVC	4.2	N55	N27B2
PE-233	245	0.32	200	uPVC	10.2	N35A	N34
PE-42	173	0.74	200	uPVC	-23.2	N7AB1	N7AB
PE-119	121	1.1	200	uPVC	-34.5	N11	N11A
PE-283	14	0.28	200	uPVC	8.7	N32A1	N32A
PE-81	187	0.1	200	uPVC	-3.2	N22D	N22D1
PE-403	182	0.18	200	uPVC	5.7	N57	N57A
PE-377	120	0.1	200	uPVC	3.1	N27B2	N27B1
PE-264	363	0.21	200	uPVC	6.7	N44	N44B
PE-296	11	0.12	200	uPVC	3.7	N29A2	N29A3
PE-393	34	0.03	200	uPVC	-1	N22	N22A1
PE-382	111	0.23	200	uPVC	7.3	N27A	N27B
PE-114	223	1.11	200	uPVC	35	N14	N11A
PE-378	146	0.1	200	uPVC	3.1	N27B1	N27B
PE-265	470	0.04	200	uPVC	1.2	N44B	N49
PE-88	301	0.23	200	uPVC	-7.2	N22A4	N22A5

PE-132	249	0.3	200	uPVC	9.3	N15A	N12A
PE-307	153	0.12	200	uPVC	3.7	N29A3	N29B'
PE-218	426	0.01	200	uPVC	0.3	N36A	N36A1
PE-390	250	0.14	200	uPVC	-4.4	N27C	N27B3
PE-62	715	0.77	200	uPVC	-24.1	N18	N9
PE-316	112	0.04	200	uPVC	-1.3	N54A1	N64A1
PE-144	259	0.16	200	uPVC	-5.1	N15A	N15B2
PE-86	70	0.21	200	uPVC	-6.7	N22A2	N22A3
PE-282	167	0.28	200	uPVC	8.7	N32	N32A1
PE-224	159	0.04	200	uPVC	-1.3	N43B1	N43B2
PE-97	170	0.06	200	uPVC	-2	N30	N30A7
PE-82	153	0.14	200	uPVC	-4.4	N22D1	N22D2
PE-364	157	0.2	200	uPVC	6.4	N55	N56
PE-392	254	0.18	200	uPVC	5.8	N27A	N22
PE-221	315	0.01	200	uPVC	-0.2	N36A	N43B1
PE-131	130	0.17	200	uPVC	5.4	N15	N15A
PE-394	213	0.19	200	uPVC	5.8	N22	N22B
PE-101	199	0.02	200	uPVC	0.5	N31D	N30A7
PE-83	60	0.14	200	uPVC	-4.4	N22D2	N22A
PE-64	14	0.24	200	uPVC	7.6	N18	N17A
PE-297	345	0.01	200	uPVC	-0.4	N29A3	N52A
PE-410	57	0.04	200	uPVC	-1.4	N24C	N24A
PE-308	345	0.07	200	uPVC	-2.2	N29B'	N52B
PE-80	293	0.07	200	uPVC	-2.3	N22C	N22D
ED-02	1	0	200	DI	0	PMDK02-5	ND-04
P-1203	1	0	200	DI	0	J-1012	J-1014
P-1200	1	0	200	DI	0	PMK02-3	J-1013
ED-01	2	0	200	DI	0	ND-48	PMDK02-5
EG-87	2	0.22	200	DI	7	FCV-BAG	RAG-1640
EG-97	52	0	200	DI	0	FCV-GAG	NG-44
P-1204	1	0	200	DI	0	J-1014	PMK02-3
P-1205	1	0.84	200	DI	26.4	PMK02-1	J-1015
ED-03	2	0.8	200	DI	25.2	PMDK02-4	ND-04
P-1958	1	0.84	200	DI	26.4	J-1011	PMK02-1
P-1839	351	0.89	200	uPVC	27.9	J-1610	J-1626
ED-35	1	0.8	200	DI	25.2	ND-48	PMDK02-4
P-1196	1	0.84	200	DI	26.4	J-1012	PMK02-2
P-1197	1	0.84	200	DI	26.4	PMK02-2	J-1724
P-1193	1	0.42	200	DI	13.2	J-1011	J-1012
P-1194	1	0.42	200	DI	13.2	J-1011	J-1012
EG-93	3	0	200	DI	0	RGA-1750	FCV-GAG

P-1758	196	0.04	200	uPVC	1.1	N12	ILu-01
PB-01	121	0	200	uPVC	0	RBOK-1715	BO-02
PB-02	443	0	200	uPVC	0	BO-02	BO-03
PB-16	616	0	200	uPVC	0	BA-07	BO-03
PB-11	753	0	200	uPVC	0	BA-07	BA-05
EG-40	3	0.24	200	uPVC	7.4	NG-75	NG-07
EG-41	80	0.24	200	uPVC	7.4	NG-07	NG-08
EG-96	369	0	200	DI	0	NG-43	NG-44
EG-95	144	0	200	DI	0	NG-42	NG-43
P-806	235	0.64	200	uPVC	20	N100U3	N106A"
P-808	32	0.61	200	uPVC	19	N106A"	N102A
EG-94	34	0	200	DI	0	NG-51	NG-42
EG-91	33	0.24	200	uPVC	7.4	NG-08	NG-09
PE-87	110	0.21	200	uPVC	-6.7	N22A3	N22A4
PE-458	254	0.53	200	uPVC	16.5	N106A	N102
PE-37	103	1.91	200	uPVC	-59.9	N4	N5A
PE-145	124	0.2	200	uPVC	-6.2	N15B2	N2
PE-460	400	0.75	200	uPVC	-23.6	N106A'	N101
PE-457	131	0.18	200	uPVC	5.5	N106A	N106A'
ED-41	286	0	200	uPVC	0.1	ND-35	ND-36
PE-456	203	0.89	200	uPVC	28.1	N106A'	N100U3
PE-46	50	1.01	200	uPVC	-31.6	N7B1	N7B2
PE-395	89	0.16	200	uPVC	4.9	N22B	N22C
PE-398	191	0.07	200	uPVC	2.3	N24A	N24A1
PE-84	53	0.15	200	uPVC	-4.8	N22A	N22A1
PE-321	255	0.1	200	uPVC	3.3	N64B	N64B1
PE-409	176	0.01	200	uPVC	-0.3	N24E	N24C
PE-422	266	0.26	200	uPVC	-8.1	N56A1	N54D'
PE-311	239	0.03	200	uPVC	1.1	N52B	N52'
PE-487	59	0.13	200	uPVC	4.1	N103	N103'
P-1832	21	0.89	200	uPVC	27.9	J-1016	J-1608
P-1836	324	0.89	200	uPVC	27.9	J-1631	J-1629
P-1835	240	0.89	200	uPVC	27.9	J-1620	J-1631
P-1841	208	0.81	200	uPVC	25.6	NN-01	ILEBO-01
P-1838	181	0.89	200	uPVC	27.9	J-1624	J-1609
P-1833	58	0.89	200	uPVC	27.9	J-1608	J-1613
P-1840	18	0.89	200	uPVC	27.9	J-1609	J-1610
P-1842	184	0.89	200	uPVC	27.9	J-1626	NN-01
PE-492	149	0.07	200	uPVC	2.2	N103C	N107
ED-39	284	0	200	uPVC	0.1	ND-33	ND-34
ED-38	42	0	200	uPVC	0.1	ND-32	ND-33

ED-40	257	0	200	uPVC	0.1	ND-34	ND-35
P-1834	141	0.89	200	uPVC	27.9	J-1613	J-1620
P-1837	215	0.89	200	uPVC	27.9	J-1629	J-1624
PE-488	141	0.13	200	uPVC	4.1	N103'	N103C
PE-462	401	0.74	200	uPVC	23.2	N106	N106A
ED-37	120	0	250	uPVC	0	ND-31	ND-32
ED-36	266	0	250	uPVC	0	RDHA-1745	ND-31
PE-381	68	0.19	300	uPVC	13.3	N27A1	N27A
PE-123	112	1.72	300	uPVC	121.3	N10	N10A1
P-1199	31	0.75	300	DI	52.7	J-1013	J-1725
PE-196	150	0.48	300	uPVC	34.1	N39A2	N39A3
PE-226	208	0.27	300	uPVC	19.2	N43B	N43B4
PE-380	118	0.19	300	uPVC	13.3	N27A2	N27A1
PE-137	351	0.63	300	uPVC	44.6	N12A4	N12
PE-509	319	0.75	300	DI	-52.7	N103	N72
P-1209	30	1.06	300	DI	75	J-1007	FCV-K02
P-1210	2	1.06	300	DI	75	FCV-K02	Rk02-1650
PE-120	204	1.7	300	uPVC	120	N11	N10A
PE-228	123	0.21	300	uPVC	-14.7	N35A	N43B3
PE-194	259	0.51	300	uPVC	36.1	N39A	N39A1
PE-465	62	0.48	300	DI	33.8	N100R4	N100R5
P-1953	50	0.75	300	DI	52.7	N68D1	N72
ED-34	6	0.36	300	DI	25.2	J-1726	ND-48
PE-238	433	0.08	300	uPVC	5.4	N35A	N46A2
P-1952	23	0.75	300	DI	52.7	J-1725	N68D1
PE-136	79	0.68	300	uPVC	48.3	N12A3	N12A4
PE-143	377	0.7	300	uPVC	49.5	N15C	N2
PE-141	114	0.66	300	uPVC	46.6	N15A1	N15D
P-1192	1	0.75	300	DI	52.7	J-1726	J-1011
PE-484	415	0.61	300	DI	-43	N105	N103A
PE-146	174	0.59	300	uPVC	41.9	N2	N12A
PE-126	136	1.7	300	uPVC	120.2	N10A3	N9
PE-198	200	0.44	300	uPVC	31	N39A4	N39A5
P-1191	23	1.06	300	DI	-75	J-1007	J-1010
PE-251	148	0.12	300	DI	-8.4	N30A8	N30A9
PE-252	61	0.12	300	DI	-8.4	N30A9	N31
PE-466	67	0.48	300	DI	33.8	N100U2	N100R4
PE-129	437	1.2	300	uPVC	84.5	N12	N11
PE-128	404	0.63	300	uPVC	44.6	N13	N12
PE-270	252	0.36	300	uPVC	25.6	N47A	N47
PE-134	261	0.68	300	uPVC	48.3	N12A1	N12A2

PE-486	244	0.66	300	DI	-46.4	N103A	N103
PE-199	195	0.43	300	uPVC	30.2	N39A5	N39A6
PE-197	215	0.47	300	uPVC	33.3	N39A3	N39A4
PE-350	279	0.39	300	uPVC	27.3	N28B1'	N28A''
PE-133	162	0.7	300	uPVC	49.7	N12A	N12A1
PE-121	213	1.68	300	uPVC	118.5	N10A	N10
PE-125	40	1.7	300	uPVC	120.2	N10A2	N10A3
PE-289	511	0.08	300	uPVC	5.3	N32	N32B
PE-200	95	0.42	300	uPVC	29.6	N39A6	N37
PE-379	167	0.19	300	uPVC	13.5	N28AA	N27A2
PE-463	191	0.43	300	DI	-30.4	N101	N100R6
PE-469	45	0.71	300	DI	-50	N100R1	RAU-1720
PE-468	203	0.71	300	DI	50	N100R1	N100U1
PE-248	128	0.11	300	DI	-7.7	N30A5	N30A3
PE-135	52	0.68	300	uPVC	48.3	N12A2	N12A3
PE-464	123	0.44	300	DI	-30.9	N100R6	N100R5
PE-357	324	0.17	300	uPVC	11.9	N28A'	N55A
PE-227	104	0.22	300	uPVC	15.3	N43B4	N43B3
PE-351	155	0.2	300	uPVC	13.9	N28A''	N28AA
PE-508	138	1.06	300	DI	75	N68D	J-1010
PE-124	97	1.72	300	uPVC	121.3	N10A1	N10A2
PE-214	260	0.41	300	uPVC	-28.9	N38B	N37
ED-05	57	0.36	300	DI	25.2	ND-05	ND-11
PE-48	23	0.88	300	uPVC	61.9	N8	N8A
ED-31	368	0.36	300	DI	25.2	ND-03	ND-27
ED-27	40	0.36	300	DI	25.2	ND-06	ND-07
PE-268	167	0.44	300	uPVC	31.3	N46	N46B
PE-281	378	0.21	300	uPVC	14.7	N46	N32
ED-15	119	0.36	300	DI	25.2	ND-18	ND-13
PE-461	130	0.08	300	DI	-5.9	N106	N101
PE-142	86	0.7	300	uPVC	49.5	N15D	N15C
ED-11	267	0.36	300	DI	25.2	ND-30	ND-28
ED-21	139	0.36	300	DI	25.2	ND-23	ND-16
ED-17	41	0.36	300	DI	25.2	ND-08	ND-09
ED-29	23	0.36	300	DI	25.2	ND-02	ND-03
ED-08	182	0.36	300	DI	25.2	ND-24	ND-26
PE-269	217	0.37	300	uPVC	26	N46B	N47A
PE-49	447	0.87	300	uPVC	61.2	N8A	N5A
ED-24	186	0.36	300	DI	25.2	ND-25	ND-19
ED-26	125	0.36	300	DI	25.2	ND-20	ND-06
PE-222	321	0.29	300	uPVC	20.8	N36	N43B

PE-359	11	0.16	300	uPVC	11	N55A	N55
PE-467	301	0.59	300	DI	41.9	N100U1	N100U2
ED-32	190	0.36	300	DI	25.2	ND-27	ND-14
PE-470	483	0.33	300	DI	23.2	N105	N106
PE-295	218	0.06	300	uPVC	4.1	N29A1	N29A2
ED-30	3	0.36	300	DI	25.2	ND-01	ND-02
ED-28	42	0.36	300	DI	25.2	ND-07	ND-01
ED-13	136	0.36	300	DI	25.2	ND-22	ND-21
ED-25	120	0.36	300	DI	25.2	ND-19	ND-20
ED-04	33	0.36	300	DI	25.2	ND-04	ND-05
ED-20	228	0.36	300	DI	25.2	ND-12	ND-23
PE-195	192	0.48	300	uPVC	34.1	N39A1	N39A2
ED-19	73	0.36	300	DI	25.2	ND-10	ND-12
ED-06	105	0.36	300	DI	25.2	ND-11	ND-15
ED-33	95	0.36	300	DI	25.2	ND-14	RDHA-1745
ED-07	157	0.36	300	DI	25.2	ND-15	ND-24
PE-354	154	0.18	300	uPVC	-13	N28A'	N28A"
PE-234	565	0.08	300	uPVC	5.9	N34	N33
PE-249	107	0.11	300	DI	-7.7	N30A3	N30A4
ED-18	43	0.36	300	DI	25.2	ND-09	ND-10
ED-23	110	0.36	300	DI	25.2	ND-16	ND-17
ED-09	263	0.36	300	DI	25.2	ND-26	ND-29
ED-22	179	0.36	300	DI	25.2	ND-17	ND-25
PE-250	118	0.11	300	DI	-7.7	N30A4	N30A8
ED-10	303	0.36	300	DI	25.2	ND-29	ND-30
ED-14	122	0.36	300	DI	25.2	ND-21	ND-18
PE-63	129	1.32	300	uPVC	93.5	N9	N8
ED-12	222	0.36	300	DI	25.2	ND-28	ND-22
ED-16	81	0.36	300	DI	25.2	ND-13	ND-08
PE-215	233	0.36	300	uPVC	25.2	N38B	N36
P-1198	1	0.55	350	DI	52.7	J-1724	J-1013
P-1206	1	0.27	350	DI	26.4	J-1015	J-1724
PE-188	211	0.72	400	DI	90	N39B	N38A
PE-186	569	0.75	400	DI	94.4	N39A	N39B1
PE-190	119	0.62	400	DI	77.5	N42	N43
PE-191	208	0.55	400	DI	69.7	N43	N43A
PE-267	469	0.37	400	DI	46.7	N44	N46
PE-507	183	0.68	400	DI	85	N68C	N68D
PE-519	290	0.71	400	DI	89.1	N62	N68C
PE-192	204	0.55	400	DI	69.2	N43A	N43A1
PE-193	266	0.5	400	DI	62.9	N43A1	N44A1

PE-266	49	0.5	400	DI	62.2	N44A1	N44
PE-187	178	0.73	400	DI	92	N39B1	N39B
PE-427	199	0.74	400	DI	92.7	N54B1'	N62
P-1954	5	0.62	400	DI	78	Rk02-1650	J-1726
PE-189	354	0.71	400	DI	89.3	N38A	N42
PE-347	118	0.57	500	DI	112.1	N54B	N54A
PE-162	526	0.77	500	DI	150.9	N82	N81
PE-349	87	0.54	500	DI	106.6	N54B1	N54B1'
PE-164	62	0.7	500	DI	137.4	N82A	N82B
PE-341	94	0.6	500	DI	118.8	N29A	N29A'
PE-343	215	0.6	500	DI	118.4	N29A''	N29B
PE-91	54	0.8	500	DI	156.2	N30A1	N30A
PE-168	119	0.69	500	DI	135.5	N82E	N82F
PE-169	120	0.69	500	DI	135.5	N82F	N39
PE-166	73	0.69	500	DI	135.5	N82C	N82D
PE-344	318	0.58	500	DI	113.4	N29B	N54
PE-348	158	0.54	500	DI	106	N54A	N54B1
PE-161	19	0.77	500	DI	150.9	N15F5	N82
PE-185	311	0.68	500	DI	133.3	N39	N39A
PE-92	40	0.8	500	DI	156.2	N30	N30A1
PE-94	118	0.79	500	DI	-155.9	N30A2	N30A5
PE-163	550	0.71	500	DI	139.3	N81	N82A
PE-167	25	0.69	500	DI	135.5	N82D	N82E
PE-342	42	0.6	500	DI	118.6	N29A'	N29A''
PE-95	12	0.76	500	DI	-148.8	N30A5	N30A6
PE-339	41	0.75	500	DI	146.6	N28B1	N28B1'
PE-165	157	0.7	500	DI	137.4	N82B	N82C
PE-340	86	0.61	500	DI	119	N28B1'	N29A
PE-98	157	0.77	500	DI	-151.3	N30A6	N31C
PE-93	30	0.79	500	DI	154.7	N30A2	N30
PE-346	84	0.57	500	DI	112.1	N54F	N54B
PE-90	96	0.79	500	DI	155	N30A	N28B1
PE-345	163	0.55	500	DI	108.2	N54	N54F
PE-130	810	0.92	600	DI	-258.8	N13	N15
PE-155	73	1.24	600	DI	-350	N15F3	N15F4
PE-159	77	1.79	600	DI	-505.3	N15F7	N15F8
PE-160	52	1.79	600	DI	-505.3	N15F8	RLU-1685
PE-107	239	0.58	600	DI	-165.2	N31A	N14A
PE-139	178	0.94	600	DI	-265.3	N15B	N15B1
PE-113	260	0.6	600	DI	-169.6	N14A	N14
PE-102	311	0.57	600	DI	-159.8	N31C	N31A

PE-156	124	1.24	600	DI	-351.5	N15F4	N15F5
PE-138	166	0.94	600	DI	-265.3	N15	N15B
P-1207	205	0.94	600	DI	-266.4	N15B1	J-1016
P-1208	187	1.04	600	DI	-294.3	J-1016	N15A1
PE-157	34	1.78	600	DI	-503.9	N15F5	N15F6
PE-127	433	0.74	600	DI	-210.4	N14	N13
PE-147	271	1.21	600	DI	-342.1	N15A1	N15F
PE-158	279	1.78	600	DI	-503.9	N15F6	N15F7
PE-154	96	1.24	600	DI	-350	N15F	N15F3