



**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

***ASSESSMENT OF PIPE FAILURE CAUSES (CASE STUDY ON CHIRO  
TOWN WATER SUPPLY DISTRIBUTION SYSTEM), ETHIOPIA***

A thesis submitted and presented to the school of graduate studies of Addis Ababa University in partial fulfillment of the degree of Masters of Science in Civil and Environmental Engineering (Major in Water Supply & Environmental Engineering).

**By**  
Masho Dekamo

**Advisor**  
Dr. Ing. Geremew Sahilu

September, 2021  
Addis Ababa, Ethiopia

**Certificate**

This is to certify that the thesis prepared by Masho Dekamo Hindeso, entitled:

*Assessment of pipe failure causes (Case study on Chiro Town water supply distribution system), Ethiopia* and submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (major in Water Supply and Environmental Engineering).

As a member of the board of examiners of the MSc, Thesis open defense examination, we certify that we have read, evaluated the thesis prepared by Masho Dekamo Hindeso and examined the candidate.

We recommend that the thesis be accepted as fulfilling the thesis requirement for the degree of Master of Science in Civil Engineering (Major in Water Supply and Environmental Engineering).

Dr.Ing. Geremew Sahilu  
(Thesis Advisor)

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

\_\_\_\_\_  
(Internal Examiner)

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

\_\_\_\_\_  
(External Examiner)

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

\_\_\_\_\_  
(Chairman, School of Civil and  
Environmental Engineering)

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

## Declaration

I declare that the work in the thesis entitled " *Assessment of pipe failure causes: the Case study on Chiro town water supply distribution system, Ethiopia*" was collected by myself under the supervision of Dr. Geremew Sahilu in the Addis Ababa institute of technology, Addis Ababa University in the year 2020. The information derived from literature has been duly acknowledged in the text and a list of references were provided. No part of this thesis was previously presented for another Degree or Master at any University.

Masho Dekamo Hindeso

Signature: -----

Date: -----

September, 2021

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## ABSTRACT

Intermittent water distribution is the key problem of many water authorities in developing countries including Ethiopia. Hence, this research was conducted to carry out a risk assessment of water supply pipe failure (burst) in the water supply system of Chiro town which is located in the eastern Oromia Region of Ethiopia. To investigate the cause of pipe burst in the town water supply distribution network, physical, pipe installation condition investigations of the distribution system and water GEMS modeling were utilized. Chiro town water supply distribution system was constructed in 2013 to 2015. More pipes were laid from 2014 to 2015 especially uPVC pipe and HDPE, but more pipe bursts were observed in uPVC pipe and HDPE pipe.

According to pipe failure (burst) history recorded in the town water supply distribution system, more types of pipe burst were found in plastic pipe (uPVC pipe and HDPE) than the other types of pipe (DCI and GI pipes). The water supply distribution piping is mainly of plastic pipes (89.17%) and 10.83 % other types. According to Chiro town's water distribution system, the investigation of the factors causing pipe failure in the system was based on considering three factors (pipe condition assessment) such as physical factors (types of pipe materials, pipe diameter, pipe installation years), environmental factors or pipe installation conditions (pipe cover, pipe bedding and backfill practiced conditions) and hydraulic parameters (internal water pressure, transient pressure and also velocity).

As per the research results, the main causes of pipe burst in the water supply system were the type of pipe materials and its PN, water pressure, poor pipe installation practices, absence of selected material pipe bedding specially at rocky area and also absence of sufficient pipe cover and back fill for plastic pipe or uPVC and HDPE pipes.

In general, frequent pipe burst in the system leads to water losses and this contributes to interruptions (intermittent) of water supply in the town. Based on pipe condition/situation assessment and the relation between the parameters which contributes to pipe failure, identify which parameter/s are more related to the cases of pipe failure than the others and develop equation based on their relationship of the parameters with the probability of pipe failures. This is significant to rehabilitate /replacement/repair and improve the reliability of town water distribution system and providing more attention to pipe burst reduction strategies which are vital for remedial measures.

**KEY WORDS:** Pipe condition assessment, pipe break/burst, water GEMS modeling, Chiro town

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### List of Acronyms

B	Burst
BHs	Bore Holes
D	Pipe diameter
DCI	Ductile Cast Iron
GEMS	Geospatial Engineering Modeling System
GI	Galvanized Iron
GIS	Geographic Information System
H	Total pipe buried depth
HDPE	High Density Polyethylene
HGL	Hydraulic Grade Line
P	Pressure
PN	Pipe nominal pressure
RC	Reinforcement Concrete
UPVC	un-plasticized polyvinyl Chloride
WDN	Water Distribution Network

## CHAPTER ONE

### 1. Introduction

In this section; background of the research, statement of the problem, research questions, research objective, significance of research, scope of research and thesis contents are present.

#### 1.1 Background

Water is one of the most essential and non-substitutable natural resources and getting adequate quantity of water with potable quality is a basic need for human life. Water distribution systems (WDS) are considered as critical component of an urban infrastructure system in the provision of water supply. The problem of pipe failure is an unavoidable and natural tendency of water distribution system; even if they are well designed, carefully protected and operated (Bantie Y., 2011). But the issue is the degree of the failure and its effect in the provision of basic water supply.

There are several factors that can contribute to pipe failure. The major ones are pipe materials, pipe age, pipe installation condition (Improper installation), internal water pressure, pressure transient, pipe corrosion, pipe diameters, external forces (soil cover, traffic load, snow, loading from building) *Predicting the Failure Performance of Individual Water Mains by Mavin (1996)*. Most water mains in a distribution system typically experience two common forms of pipe failure (structural and functional) under normal operation. Although the magnitude of a pipe failure can vary on a case by case basis, they typically occur in the form of a break (burst) along the physical structure of the pipe.

In Ethiopia, the towns (cities) are expanding rapidly with increasing population and resulting an increase in water consumption that contributes to the general increase of water demand in urban areas. But, most water supply services of towns in Ethiopia are unreliable in providing adequate water. As Behaylu (2016) by his dissertation work states, almost all cities in the country have frequently experienced service

failures and lack of supply due to non-functionality of different schemes in causes of some design and construction conditions.

According to Chiro town water supply service office, the common problem in the town water system was interruption of water supply for consecutive days due to the frequent pipe burst and also pump failure in the town water distribution system. Thereby, there is inadequate amount of water supply and loss of water in the town. Therefore, this research works to identify the main causes of pipe failures in Chiro town water distribution system by using pipe condition assessment.

## **1.2 Statement of the Problem**

The common problems in the Chiro town concerning to water supply are frequent pipe bursting of water supply pipe and significant water loss from the system due to the leakage and also frequent pump failure. This leads an interruption of water supply and reducing the per capita water supply in the town and also impacting the health of the community due to less water supply and possible contamination of the distribution system. The causes of pump failure is not included in the scope of this thesis. The town water supply distribution system constructed from four types of pipes such as uPVC pipe (for transmission line and some in distribution line), DCI pipe (for transmission line and some in distribution line), HDPE pipe (for distribution line) and GI pipe (for distribution line). In water distribution line, more lines (greater than 85%) are covered by uPVC pipes and HDPE pipes and frequently pipe burst/failures were appeared in these plastic pipe. For this reason, this study paper was prepared to address the current and future pipe burst for Chiro town existing water supply distribution system.

## **1.3 Research questions**

- 1) What are the main causes of pipe burst?
- 2) Which areas of the distribution systems are affected by pipe burst?
- 3) Which types of pipes are frequently bursting?
- 4) How can one minimize the risk of pipe burst?

## **1.4 Objective**

### **1.4.1. General Objective**

The main objective of this study is to investigate the causes of pipe burst in the Chiro town water supply distribution system and forward recommendations to minimize the frequency of pipe failure so that the interruption of water supply can be reduced.

### **1.4.2. Specific objectives**

- Identify the causes of pipe failure
- Identify parts of the water supply system where frequent pipe bursting is encountered
- Investigate which types of pipes are frequently bursting
- Recommend measures to be taken by the water supply utility to improve the situation

## **1.5 Scope of the study**

The objective of this thesis is to present the important concept of pipe failure assessment in the system (Chiro Town water supply distribution system) identify the causes of pipe failure and also to minimize risk of pipe burst in the system and ensure sustainability of water supply to consumers. Causes of pipe failure assessment in this study based on physical, environmental and Hydraulic factors and finally identify which factors/factor is more the causes of the pipe burst in the system.

## **1.6 Significances of the study**

Significances of this study will contribute to the understanding of the causes of pipe failure in the Chiro town water distribution system and could give guidance for Chiro town water supply and sanitation utility on measures to be taken to minimize the risk of pipe burst appeared in the system. And also this study can contribute for the reliability of the water supply system in the town by reducing interruption through the implementation of recommended measures and ultimately improve the health status of the community through provision of ample water with less risk of contamination.

## 1.7 Structures of the thesis

This thesis consists of five chapters such as **introduction** which involved background of the study area, statement of the problems, research questions, research objective, scope of research, significant of research and thesis contents, **literature review** this intricate the review of different literatures and different international journals concerning the title (objective of the research) to understand issues in the area of the research and identify gaps, **materials and methods** this elaborate the materials used in the research and procedures to achieve the research objective, **results and decisions** which include research output with decisions(calibration and validation work) and **Conclusion and recommendation** which concern the summary of the research and future works and also limitations of the works and recommendations.

## CHAPTER TWO

### 2. Literature Review

This chapter includes pipe break history, pipe conditional assessment, theory and principles of pipe conditions assessment, main causes of pipe failure (burst) factors (e.g., Physical, Environmental, operation/hydraulic), Pipe failure mechanisms, pipe failure classifications, frequency of pipe failures, consequences of pipe failures, pipe failure management cycle, Hydraulic simulation of pipe network, water hammer and conclusion.

#### 2.1. Pipe breaks history

Pipe breaks (bursts) are a regular occurrence in water distribution systems. Commonly, water supply pipe burst occur when the residual strength of a declined pipe become inadequate to resist the force imparted on it (Skipworth et al. 2002) which means water supply pipe burst or break due to the different factors such as either physical, environment and hydraulic or all factors beyond the resisting capacity of the pipe. From an expressions point of view pipe bursts are usually denoted to also as breaks or failures and also links to leak when losses in water distribution networks are analyzed (Farley & Trow 2003). According to the concept of (Kleiner & Rajani 2001), the water supply pipe failures were classified into two. Such as structural failures, means moderate the pipe structural failures and its ability to withstand coming different types of pressures imposed upon it whether the internal or external pressure due to the corrosion of internal surfaces of water supply pipe. This condition occurred on different types of pipes than the other types of pipes due to the soil and water conditions. DCI and GI pipes are more susceptible for this condition than uPVC and HDPE pipe. These situation leads to different problems such as an economic burden for the costs of pipe repair and replacement and social impact due to service interruptions. But there is a different ideas concerning the causes of water supply pipe failure. Some researchers were discussed on the roots of pipe failure having water supply distribution system by developing different models.

## 2.2. Develop some equation to calculate the probability of pipe failure

Having different pipe failure factors and their relationships, different model (formula) was developed by different researchers to detect the main causes of pipe failure/burst in water supply distribution system. From these researchers, some are illustrate as this with respect to their developed equation/formula with their discussed ideas with the others ideas or developed equations (Shamir & Howard 1979; Walski & Pelliccia 1982 and Mavin 1996; Kleiner & Rajani 2001, Clark et al. 1982; Kettler & Goulter 1985, Lei & Saegrov 1998, Herz 1996). These researchers were discussed having statistical or arithmetic development of different equations concerning different factors of pipe failure causes or parameters. Example Shamir and Howard (1979) developed the following non-linear equation/formula having an age of a pipe is the main causes of the pipe burst causes in the water distribution system and calculate the probability of the pipe burst.

$$N(t) = N(t_0) e^{A(t+g)} \text{-----} (1)$$

Where:  $N(t)$  = Number of breaks (Per pipe, per unit length, per year)

$N(t_0)$  = Number of breaks at the year of installation

$A$  = Breakage rate coefficient (years<sup>-1</sup>)

$t$  = Time period between the occurrence of a given break and  
the present time when analysis is being conducted (years)

$g$  = Age of the pipe at time ( $t$ ) in years

But Walski & Pelliccia 1982; Clark et al. 1982; Kettler & Goulter 1985 was not believe the idea of the main causes or parameter of the pipe burst is a pipe age only and also other parameters are contribute the pipe failure in addition to a pipe age. Such Parameters are types of materials and sizes of pipe. So, based on Shamir and Howard (1979) developed model (equation), Walski & Pelliccia 1982; Clark et al. 1982; Kettler & Goulter 1985 modify the model as the following model.

$$N(t) = C_1 C_2 N(t_0) e^{A(t+g)} \text{-----} (2)$$

Where: N (t) = Number of breaks (Per pipe, per unit length, per year)

C1 = Ratio between the frequency of a pipe's breaks with the overall break frequency of that pipe's material type

C2 =Ratio between the frequency of a pipe's breaks as a function of its size relative to the break frequency of that pipe's material type.

N (t0) = Number of breaks at the year of installation

A = Breakage rate coefficient (years-1)

t = Time period between the occurrence of a given break and the present time when analysis is being conducted years

g = Age of the pipe at time (t) in years

From investigation of the relation between the pipe diameter and pipe failure rate was done, the relationship was found between pipe diameter and failure rate was inverse relationship. That means small diameter pipes showing higher breakage rates than their larger due to the thickness of the pipe wall.

Again other researcher (Herz 1996; Lei & Saegrov 1998) argue pipe age and pipe diameter are not only fully identify pipe failure causes. So, in addition to pipe age and pipe diameter; pipe materials, soil types, pipe covers or land use above pipes were integrated to the effect of the pipe failure.

In order to accuracy in forecasting pipe failure, Clark et al. (1982) develop a model concerning different parameters which causes of the pipe failure or burst (pipe installation or pipe age, pipe diameter, internal water pressure, pipe materials, pipe length which pipe cover along the pipe distribution, percentage of pipe covered by residential and industrial) as the following:

$$NY = 4.13 + 0.338(D) - 0.022(P) - 0.265(I) - 0.0983(RES) - 0.003(LH) + 13.28(T) \text{-----} (3)$$

Where: NY = Expected number of failure event in the system per year

D = Diameter of the pipe in question (inches)

P = Absolute internal pipe pressure (lbs/in<sup>2</sup>)

I = Percentage of pipe covered by industrial development

RES = Percentage of pipe covered by residential development

LH = Length of pipe exposed to rock soil/ soft soil conditions

T = Pipe material (0= for reinforced concrete, 1= for other pipes)

After analysis of the Clark et al. model to calculate the number of expected repairs a pipe may after first break occurrence by using the following exponential equation:

$$REP = (0.1721)(e^{0.7197T})(e^{0.0044PRD})(e^{0.0865A})(e^{0.0121})^{DEV}(SL)^{0.014}(SH)^{0.069} \text{ ----- (4)}$$

Where: REP = Number of expected repairs after the first failure event

T = Pipe material (0 = reinforced concrete, 1 = Other pipes)

PRD = Pressure difference before and after first failure (lbs/in<sup>2</sup>)

A = Age of pipe from its first repair event (years)

DEV = Percentage of urbanized land beneath the pipe

SL = Surface area of pipe exposed to moderately rock soil for plastic pipe /corrosive soils for GI/DCl pipe

SH = Surface area of pipe exposed to highly rock soil for plastic pipe /corrosive soils for GI/DCl pipe

Shamir and Howard (1979) developed equation is the main cause or idea rise to calculate pipe failure in the water distribution system and the other researchers are having the concept of this developed equation and expand the articles/trainings having calibration and validation works within a coefficient of determination ( $R^2$ ) value approaches to 1.

### 2.3. Pipe condition assessment

A condition assessment is any direct or indirect way to estimate the condition of pipelines and, as a result, better determine the probability failure of assets (pipes) and make a decision for their management. Condition assessment of water pipes are requires to analysis the existing problems and develop an alternative for future plan to avoid pipe failure risk (Enactment evaluation of pipe conditional assessment is

necessitate to address the pipe failure in the water supply system). But, Condition assessments of water pipe evaluations are often require a different parameters (data) about laid pipe and more time to identify which parameter or parameters are leading to pipe failures (Hunaidi, 2010).

### **2.3.1. Theory and principle of pipe condition assessment**

Gradual weakening of pipes within a water distribution system is an estimated issue that is recognized among causes and water supply asset managers. The structural weakening of water mains (Transmission, distribution and service lines) and their failures are affected by a number of factors, including pipe material, pipe diameter, pipe age, soil type, climate, traffic loading, internal water pressure changes and pipe installation condition. However, the physical processes that lead to pipe bursts/breaks are very complex and not fully understand due to the major pipes are not practically observed on the earth rather buried under ground. So, there is lesser data present about how the pipe failures (Rajani, B. and Kleiner, Y., 2010). But, traffic loading and climatic conditions are beyond this thesis.

### **2.3.2. Causes of pipe failure**

According to Rajani and Kleiner (2001) the factors that contribute to a particular or specific pipe failure can be described in three main groups:

- (a) physical factors (pipe material, diameter, age, pipe installation condition)
- (b) Environmental factor (pipe bedding and backfill, pipe location/topographic area, trench excavation, soil type, pipe corrosion, etc.)
- (c) Hydraulical factor (internal water pressure, transient pressure, flow velocity, etc.)

Since different factors can contribute to the failure of pipes in a water distribution system, pipe failure model is a complex process (see Table 1). But, the impacts of each factors on specific pipe not the same or one factor is high risk than the others. Still now, no complete or comprehensive developed model was appeared due to the variable environmental conditions and lack of relevant data (Kleiner et. Al., 2001).

### **2.3.2.1 Physical factors**

#### **I. Pipe Material**

Town water distribution system may be constructed from different types of pipes. Such as cast iron, ductile iron, polyvinyl chloride (uPVC), high-density polyethylene (HDPE), asbestos cement (AC), steel, and concrete. Different types of pipe could be affected due to material made from. Which means either metal, cement or plastic materials. When compared to pipe failure causes in water supply system, the degree of impact due to a single factor is greater in one type of pipe than the other types of pipes. So, a pipe material is one of the physical factors which can lead pipe break/burst due to different factors. Water supply pipe laid can be affected by external pressures, internal water pressure (e.g. water hammer) and environmental conditions (e.g. temperature). But, the degree of impact is different with respect to the type of a pipe. HDPE and uPVC pipes are more affected by internal water pressure and environmental conditions than the other types of pipes (Wood Andrew and Barbara Lence, 2006). But, temperature is beyond this research. In this study concerning four types of pipe materials which found in the system (Chiro Town water supply distribution system). Such as ductile iron, polyvinyl chloride, high-density polyethylene and galvanized iron (GI) pipes.

#### **II. Pipe Diameter**

Pipe diameter is one of the physical factor which is affecting pipe failure rates. Based on the size of the pipe different studies had been determined that small pipe diameter is more susceptible for break/burst rate than the large diameter (e.g. Boxall et al., 2007). According to Shamir and Howard (1979) and Walski and Pelliccia (1982) investigated about the water supply pipe failure rate due to a pipe diameter, the pipe break/burst rate is inverse relation to pipe diameter. This is due to the pipe wall thickness. Means, a pipe which is a large diameter has higher wall thickness than a pipe which has a small diameter even if they have the same material and applied the same situations (Cooper et al., 2000). The failure level related with medium and large diameter of pipes are remained fairly constant over time while small diameter of pipes were found to have an

increasing risk rate (Christodoulou 2012). Due to the wall thickness and less bending stress/pressure to resist incoming load above pipe nominal pressure.

### **III. Year of installation**

Year of installation/pipe age is one of the factor that contribute pipe break/burst rate in water supply distribution system. Year of installation is show the length of time that a pipe has been in operation and bare to the surrounding environment with in a both internal and external loading. The life time of the year of installation with in the good operation is less pipe failure than the pipe which poor operation within the exposed surrounding environment / under the ground earth. Different types of pipes can easily susceptible with different pipe failure mechanisms with time span of pipe from exposed to the surrounding environment with in a design period of the system. So, the pipe age can be measured as a replacement of pipe. And also standards for pipe installation have progressed/advanced over time to be successful the system. For example, in BWA proper installation procedures were not imposed until the late 1990's. So, it can be caused that pipes installed before this period are more vulnerable to failure than pipes installed after this period and different pipe installation years are associated with different failure probabilities. Pipe age can also be determined from pipe installation year (Mackey, et al., 2014). Barbados Water Authority (BWA) study pipe failure factors in water distribution system of Barbados. In this investigation/study includes the different pipe failure factors such as pipe material, pipe diameter, pipe installation year, maximum demand flow, traffic loading, soil type and slope. Basically, each factor was broken down into parameters and each parameter was given a score based on its theoretical significance to pipe weakening. Risk levels were allocated to parameters according to parameter scores/grades: Low risk, Medium risk and High risk. This study components of the water distribution system were installed in the early 19th century, and before 1997 there were no pipe installation procedures in effect due to a lack of implementation of standards (Halcrow Inc., 2012).

Generally, the major constraints/limitations of this study (physical factors) were the absence of water pressure data within an analysis and also absence of time constraints

that did not allow for additional time to allocate other data resources or allow for a full assessment of the entire water distribution system.

#### **IV. Pipe Length**

The length of a pipe may be expected to be related to failure number as a linear function. If pipes are layout in a homogenous/uniform surrounding, failure rate will not be impacted by a single pipe length and unless failure number will increase linearly with length of similar types of pipe in water distribution system of inappropriate conditions for the pipes which laid for and in other way, if pipe length between one node to the next is not uniform surrounding along the distance (not straight-line) failure rate will be imparted by pipe length (Haestad Methods, et al., 2003).

##### **2.3.2.2 Environment factors**

###### **I. Bedding Condition**

Bedding support is an important part of the pipeline installation and the pipe must be placed in a proper bed. Bedding type is determined by a number of factors, including pipe material, size, and surface load and working pressure. Ideally, a pipe should be supported uniformly over its entire length or free from irregularity surface, although this may change over time due to external or internal disturbance, if a pipe lacks good support. The trench bottom should be relatively smooth and free of rock. When rocks, boulders, or large stones are faced which may cause point loading on the pipe. Normally, pipe bedding filled with selected materials having 10-15cm thick (Design, installation, testing and maintenance of services for supplying water for domestic use, 1987). Pipe bedding with selected materials (free-flowing materials) is the main parties to prevent pipe from break/burst especially for plastic pipes which laid in rock area.

###### **II. Pipe cover and backfill**

Pipe cover and backfills are the most parts for resist incoming pressure which in the surrounding of the laid water supply pipe. Backfill is one of the factor to lead pipe failure if it was the absence of it. Pipe cover and Backfill may consists of the excavated materials, if it is free from unsuitable matter such as large pieces of clay, large boulder stone. Backfill provides the primary support against lateral pipe twist

and pipe cover offers to prevent pipe from incoming vertical load and against vertical twisting/deformation. The minimum pipe cover should not less than 15cm over the pipe laid and should be free of large rocks and debris. Normally, pipe cover should be 45cm having three layers (15cm for first, 10cm for second and 20cm for final layer) (Design, installation, testing and maintenance of services for supplying water for domestic use, 1987).

### **III. Buried Depth**

The total pipe buried depth is the sum of laid pipe diameter and pipe cover which laid over a pipe. Good pipeline installation, make available adequate buried depth. So, that overhead pressure does not impact the structural failures of a pipe. It has been described that defect rates decrease as depth increases and vice versa (Davies et al., 2001).

### **IV. Soil types**

Soil condition affect the water supply pipe which laid through it by the means of which the soil condition to the laid pipe. That means pipe corrosion if the laid pipe was rather than plastic pipe and the soil has low PH or acidic soil and plastic pipe failure/burst if structural soil condition (rocky soil) which pipe laid through it. If the soil environment which pipe laid is rocky soil and pipe laid through it is plastic pipe, must have sufficient pipe bedding practiced and back fill with selected materials in order to reduce the pipe failure due to structural soil types (Clark et al. (1982)).

#### **2.3.2.3 Operational/ hydraulic factors**

##### **I. Pressure**

The hydraulic design of water conveyance and distribution systems requires thorough calculations due to the significant impact of each component on the overall operation. Hydraulic design mainly study with pressures and hydraulic grading and also flow velocity in the system. These pressures measures as a minimum/maximum pressure required at a most critical point of the system. The minimum pressure requirements usually depend on the policy or rule of the county. This pressure is designated based on the height of the building found in the town and also maximum pressure limitations are

required to reduce the extra cost of pipe strengthening due to a direct relationship of a pressure in the system. According to the policy or rule of a country, if the height of the building found in the town required above nominated (acceptable ranges) of pressure, it will be provided internal booster for the building to attain water at the top of the building. In general communication, pressure greater than 60-70m should not be accepted in most countries except some countries town such as (Amsterdam/NL, Rio de Janeiro/Brazil  $\pm 25$ , Chicago/USA  $\pm 30$ , and Rome/Italy  $\pm 60$ ) the positive or negative sign ( $\pm$ ) indicates the constructed building position in the town either developed underground /above ground level and also velocity of flow in the pipe must lies between 0.6-1.5m/s in normal working the system (Kujundpi-, 1996). In the world, different countries used a different hydraulic design values (acceptable ranges) to be used in the water supply distribution system. These are listed in the following table.

*Table 2.1 Pressures in world cities*

City/Country	Minimum-maximum pressure (m)
Amsterdam/NL	$\pm 25$
Wien/Austria	40–120
Belgrade/Serbia	20–160
Brussels/Belgium	30–70
Chicago/USA	$\pm 30$
Madrid/Spain	30–70
Moscow/Russia	30–75
Philadelphia/USA	20–80
Rio de Janeiro/Brazil	$\pm 25$

Assessment of pipe failure causes (the Case study on Chiro town water supply distribution system), Ethiopia, Msc. thesis

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Rome/Italy	±60
Sophia/Bulgaria	35–80

Source: Kujundpi-, 1996

Pipe burst was occurred due to internal water pressure especially plastic pipe when pressure is beyond the maximum pipe resisting capacity (above pipe nominal pressure). Internal water pressure seems to be an inappropriate parameter proportional analysis. Means difficult to identify in simple way. So, pressure is one of the factor that contribute to a pipe burst rate in nominated system but it is a complex mechanism (karaa and Marks 1990). The causes of internal water pressure is result from air bubbles (water hammer) which leads to a pipe burst/break (Kottmann (1988). Internal water pressure increases because of a higher water demands at the end of the pipe laid. This may be leads to pipe burst due to operational factors change of flow direction and also due to demands variations (Andreou (1986). Similarly, Kowalewski (1976) made an investigation of the pipe break variations in Berlin for the effects of water demand variations. According to a Kowalewski (1976), when Compared the hourly and weekly demand in winter and summer months, as shown on Fig 2.1 that increased pipe burst/break rate during the morning on days but not on winter days due to a high water demands in the town. In Berlin, the water demand is higher for the winter period than the summer period. Due to the water demand is less in the summer period the pipe burst was appeared in this seasons than the winter because of supplied water stay in the pipe for a long time having a sufficient pressure.

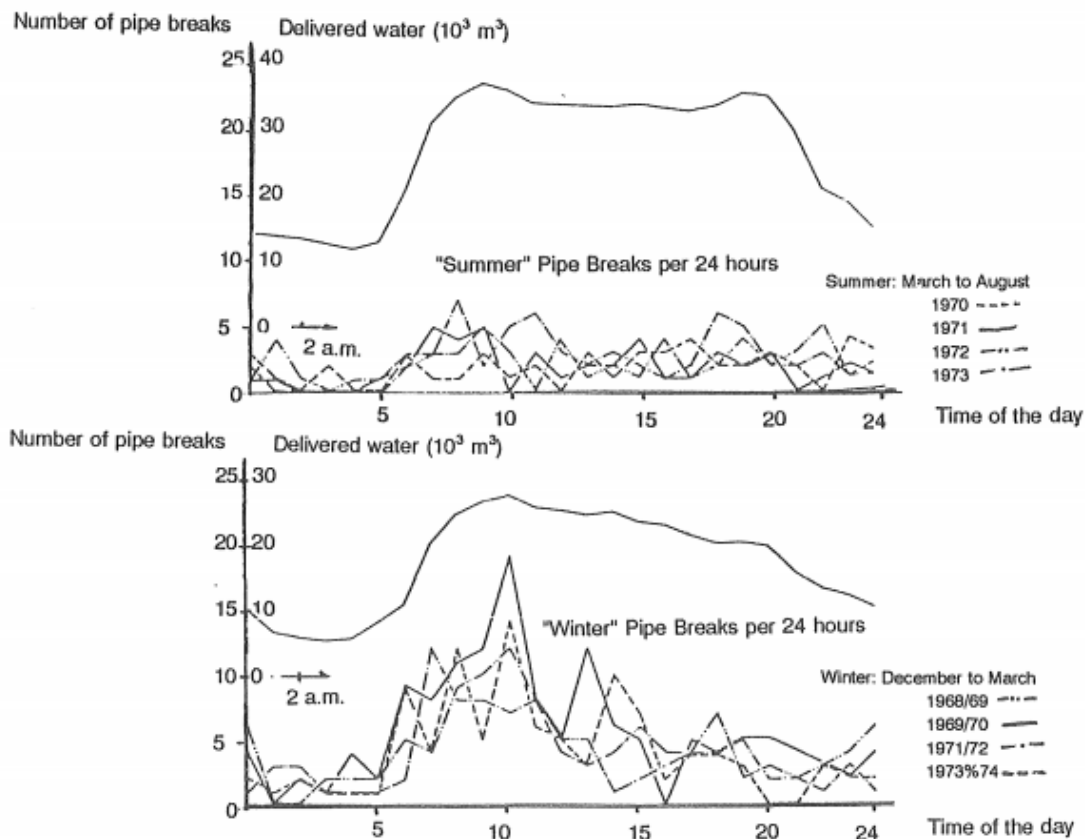


Figure 2.1 variation in hourly pipe breakage in summer

## 2.4. Pipe failure mechanisms

Pipe failure type defines the actual mode in which pipe break/bursts. The failure mechanism varies depending on the material types and the diameter of a pipe. According to O'day (1982), Pipe failure types have been classified into three main groups:

### I. Circumferential cracking

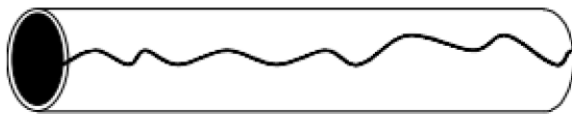
Circumferential cracking is a type of pipe failure due to a bending (twisting) forces applied on a pipe which result from soil movement, thermal contraction or third party interference. This mechanisms are mainly appeared on small pipe diameter than large diameter due to the pipe wall thickness especially cast iron pipe and uPVC pipes. This mechanism or phenomenon as shown on the (figure 2.2) and also asbestos cement water main breaks in Canada City almost 90.9% of all pipe failures due to this mechanisms (In Hu and Hubble, 2005).



*Figure 2.2 Circumferential cracking*

## **II. Longitudinal cracking**

Longitudinal cracking is a type of a pipe failure due to different types of loading either internal water pressure or external loading or combinations of the two factors. This phenomena is more common in a large diameter of pipes. The types of pipe which was susceptible for this mechanism is uPVC. This longitudinal cracking could be expanded from initial along the length of pipe line to opposite sides of a pipe like on the (figure 2.3) in the following.



*Figure 2.3 Longitudinal cracking*

## **III. Bell splitting**

Bell splitting (Figure 2.4) is most common in small diameter cast iron pipes. The main reason for bell splitting is the sealing of the joints. Originally, the joints were sealed using lead. In the 1930s and 1940s the lead was substituted by leadlight which, as a non-metallic compound, which has a different thermal expansion coefficient than lead. This mechanism, at low temperatures, can cause bell splitting.



*Figure 2.4 Bell splitting*

In addition to the three pipe failure (break/burst) types described above Makar et al. (2001) introduced the following failure methods:

### A. Corrosion pitting and blow-out holes

Corrosion pitting and blow-out holes are widely accepted that corrosion is an important factor that plays a major role in the pipe failure process. A corrosion pit (Figure 2.5 a) reduces the pipe wall thickness and mechanical resistance of the pipe wall. When the wall is thinned to a certain point, the internal pressure blows out-holes (Figure 2.5b). The size of the hole depends on the distribution of corrosion and the pressure in the pipe. This is due to acidity of the water and soil which pipe laid throughout and especially a type of pipe which susceptible for this scenarios are different metallic types of pipes and sometimes cement types of pipes.



Figure 2.5 (a) corrosion pitting and (b) blow-out hole

### B. Bell shearing

Large diameter pipes are not likely to suffer from a circumferential failure. Instead, large diameter gray cast iron pipes fail by having a section of a bell shear off as shown in Figure 2.6. The simple compressive loading is likely to cause a longitudinal crack that spreads along the length of the pipeline. Bending, however, often results in the occurrence of bell shearing.



Figure 2.6 Bell shearing

### **C. Spiral cracking**

Spiral cracking (Figure 2.7) is a rather unique failure mode that sometimes occurs in medium diameter pipes. The initially circumferential crack spreads along the length of the pipe in a spiral fashion. In history, this type of failure is associated with pressure surges, but it can also be associated to a combination of bending force and internal pressure.



*Figure 2.7 Spiral cracking*

### **2.5. Pipe failure classification**

Based on reported and unreported situations, pipe failure grouped into two. This situations are based on the degree of impacts on the system (water supply distribution system) in cases of water losses. The term break/burst and leaks in water supply distribution system are different meanings and different degree of impacts on the system. Pipe breaks (bursts) result in a clear disruption of service and require some kind of repair action whereas leaks are associated with the term 'unaccounted for water' and represent a different kind of pipe failures. In general, a break (burst) in a main water supply requires emergency repair whereas a leak does not. Normally, failures that result in the appearance of water on the ground surface are reported and therefore can be referred to as reported bursts/breaks and depending on the environment of the pipe, in some cases even a large discharge does not appear on the surface and therefore will not be reported. Such failures are referred to as unreported bursts/breaks and are running until they are identified during an active leakage control program (International Water Association (IWA) guidelines (EUREAU; 2001; Lambert and Hirner; 2000).

### **2.5.1. Frequency of pipe failure**

Some factors have been indicated in different literatures to have an influence on the frequency of pipe failures or breaks (bursts) are Pipe age, internal water pressure, pipe installation conditions, pressure transient, material types and diameter of pipes are the main factors that influence the frequency of pipe burst in the water supply distribution system. Several studies have been indicated the pipe failure frequency will increase with time. As grow older and older the system pipe failure frequency will increase and also suddenly rupture the pipe due to different loads applied on the laid pipe either external or internal loads or the combinations of the two. But, pipe failure frequencies are different from pipe to pipe based on the types of materials which made from and also due to the pipe diameter in cases of the pipe wall thickness. In many study indicated that pipe age is predominant for pipe failure causes than the other factors. The quantity of pipe failure frequency in particular point or system is measured in annual number of pipe break per kilometers. (Makar and Kleiner (2000)).

### **2.5.2. Consequences of a pipe failure**

Due to a pipe failure, there are different losses could be appeared. According to a suggestion of Makar and Kleiner (2000), these losses can be divided into three main categories. These are direct losses (due to the failure of the pipe in the system, interruption of water to the consumers and costs for pipe repairs/ rehabilitations/ replacement), indirect losses (cost of water supply due to the outage of water) and social effects (costs) losses (decrease public in trust due to an interruption of the system and cost of water quality treatment).

### **2.6. Pipe failure management cycle**

Since pipe failure has become quite a common event in the urban water supply systems, failure management is a part of the everyday operation of pipelines and pipe networks. Based on the timing of failure management activities with respect to the failure itself, two types of pipe failure management procedures can be defined. Such as proactive failure management and reactive failure management. Proactive failure management is a pipe condition assessment method that is used to examine the current

situations of the pipe. Based on the results obtained from situation assessments of the pipe water supply distribution system, to estimate the probability or chance of the pipe failure. And also based on estimated risk of pipe failure, the decision is made whether the pipe needs to be repaired/replaced/rehabilitated. The repair/rehabilitation can be done by schedules due to prevent the interruption of the services. In general, proactive is the process that to be estimated the probability of pipe failures and predict the pipe failure causes before reactive process. But, reactive failure management is applied if proactive process is not to be executed. In other word if proactive pipe failure management is wisely executed the reactive pipe failure management will be minimized (Makar and Kleiner (2000)). So, the causes of pipe failure detection is the part of this thesis and pipe condition assessment is the main process to identify which factors of pipe failure was appeared for all types of pipe in the system (Chiro Town water supply distribution system).

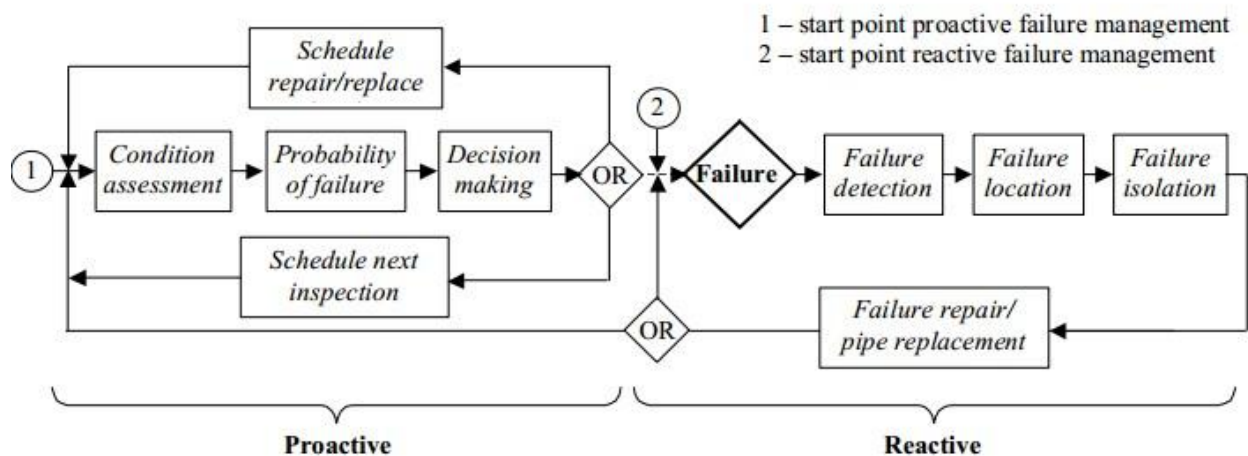


Figure 2.8 The pipe failure management cycle

## 2.7. Hydraulic modeling

### Review of water distribution systems modeling and analysis software

There are different types of soft wares used to simulation and analyze of water distribution systems. These modeling soft wares are available in market are of free\_ wares as well as commercial and used for analyzing development of new water distribution systems or managing (analyzing) the existing condition of water distribution

systems. Those soft wares are reviews as the following based on their different aspect of specialty. Finally, dedicate the software which favorable for the develop risk assessment for pipe rehabilitation and replacement for this thesis (Chiro town water distribution system).

**Water GEMS** is a good, all-inclusive and easy to use water modeling and analysis software with the advancements/progresses in system optimization, platform or display places with Arc GIS and model building. Water GEMS is a super-set or a father of Water CAD. Water GEMS is well-organized and useful modeling software which helps to understand the manners or behaviors of a system. Water GEMS software is a commercial software used to calculate pipe flow and water pressure analysis, fire flow, water quality simulation/model, asset management (asset renewal or renovation/repair) and also nitrated/model with Arc Map with multi platforms of what executed or designed or geospatial rather than the other software (Sonaje, N. P., & Joshi, M. G., 2015). **Water CAD** is a type of water software used to assessment of water demand, water distribution system analysis (hydraulic analysis), identify water leakages and operational conditions and lastly CAD interoperability (Sonaje, N. P., & Joshi, M. G., 2015). **EPANET** is an open source or freeware software used to analysis hydraulic performance of water distribution system, water quality simulation. But EPANET cannot be used to compute water hammer in the system, cannot simulate pipe bursting, cannot evaluate the consequences of the occurrence of air inside the system, and cannot evaluate cost analysis and material list (Sayed, M. A., Gupta, R., & Tanyimboh, T. T., 2014). **Hydraulic CAD** is an open source or freeware software used to analysis of hydraulic performance of water distribution and finally integrated in AutoCAD using industry standard EPANET simulation ad modelling engine/machine (Sokol, J., Grant, F., Sheline, C., & Winter, A. August, 2018). **Branch (2014)** is an open source water distribution system optimization software which is built and developed to design branched Water distribution system alignments. This software takes careful input data like pipe and reservoir elevation, length of pipe in the system having demand nodes to set cost as a function to minimize overall cost of the build system (Goh, B. K., Tan, D. M., Ho, M. M., Lim, T. K., Chung, A. Y., & Ooi, L. L., 2014). **Synergi Water** is a

hydraulic modeling and simulation software package for modelling and analysis of closed conduit system of pipes, regulators/device, valves, pumps, reservoirs, tanks and wells (McNutt, M. K., Camilli, R., Crone, T. J., Guthrie, G. D., Hsieh, P. A., Ryerson, T. B., & Shaffer, F. (2012).). **HYDROFLO3** is a modernized HYDROFLO series version and it is used for water distribution system analysis software. It can model a system with up to 10 sources, 9 branches and approximately 1000 elements. This means used for wide range of water distribution systems elements and components and also used in an industrial applications/uses, simulation of treatment plants and fire-flow analysis (Sonaje, N. P., & Joshi, M. G., 2015).

Generally, the selection of the software is based on the compatibility/specially and functionalities of the software on situations of the study area. Water GEMS software was advanced software for analyze and asset management (asset renewal or renovation) of existing water supply distribution system than the others software. The study appeal on Chiro Town water distribution system concern to develop risk assessment model for pipe rehabilitation and replacement. So, water GEMS software applicable software for this study than the others soft wares.

## **2.8 Water hammer**

Pressure transient is one of the factor that leads to a pipe burst in water supply distribution system. Pressure transients (water hammer) occurred in the water supply distribution system due to the operational system such as suddenly valve closures and open and also due to a different fittings appeared on the line. This leads to change the water flow direction (disturbance of the water flow) or either an acceleration or retardation of the water flow. Due to the disturbance of water flow, occur air bubble in the pipe this makes rise the pressure (pressure surge) in the pipe. In cases of this scenarios different events were appeared in the system such as pipe burst (rupture), damage pipe fixtures, damage of a pump, foundations of pipe laid due to vibration formations, buckling of plastic pipe and thin walled steel pipes, disintegration of the cement lining of pipes, formation of macro cavitations on the pipe. In general, in a pipe system of water mains, water flows with certain velocity steadily in the mains and branch pipes. However, for an instant/immediate closure of

a valve, huge pressure develops in the pipe system. The magnitude of the pressure under a transient condition is expressed by Joukowsky's equation of instant valve closure is listed in the following.

#### Critical time

Time for the pressure wave to return to the source of the wave.

$T_M = 2L/C$ , L= length of pipe,  $T_M$ = time of retardation

#### Pressure rise due to water hammer

Wave celerity, c is found by expression of

$$C = \frac{9900}{\sqrt{(48.3 + (K.D/e))}}$$

C=wave celerity (m/s) (Wave propagation velocity "C") g=accelerate due to gravity,

D=pipe diameter

e=pipe thickness

k=modulus of elasticity of pipe material

k=1, for DCI pipes,

k=18, for uPVC, HDP

#### Simple calculation of transient impact

Joukowsky's formula for rapid closure of the valves

$$\Delta H = \frac{a}{g} * \Delta v$$

Where: g= gravitational constant

(9.81m/s<sup>2</sup>) A= pressure wave speed

$$\approx \frac{1200m}{s} \text{ in cement pipe}$$

$$\approx \frac{300m}{s} \text{ in plastic pipes}$$

Ratio  $\frac{a}{g}$  range from about 30 to 120

If  $\Delta H = 100 * \Delta$ , stopping 1m/s causes in upsurge of 100m. And also be aware of low pressure and thrust forces.  $\Delta v$  = Change in velocity (m/s) (Arries & Anderson, Ghidaoui et. al. 2005).

## 2.9 Summary

The literature review shows that pipe failure (i.e. break or burst) in a water distribution network is a complicated event, which usually results from a combination of several factors such as physical factors (types of materials, pipe age, poor installation of pipe, pipe diameters, etc.), Environmental factors (soil type, poor practices of the pipe environment (pipe cover, pipe buried depth, pipe bedding and backfill)) and hydraulic conditions (internal water pressure, pressure transient or water hammer due to sudden change of the direction of the water flow). Pipe failure patterns between different water distribution networks, and also among the pipes of a given network, are highly variable. Water network must be analyzed individually to determine which variables (parameters) are responsible for pipe failures. Generally, this study has implemented for pipe network develop of risk assessment model based on the pipe failure factors (pipe condition assessment) for pipe rehabilitation and replacement in the system for sustainability of the system (reliable of water supply in the town).

## CHAPTER THREE

### 3. Materials and Methods

This chapter contains basically the description of the study area, materials and tools for data collection, pipe condition assessment for pipe burst, pipe burst history and methodology to model existing Chiro town water supply distribution system using water GEMS.

#### 3.1. Description of the Study Area

Chiro town was established in 1930 and the new town administration was established in 2010 and it is located in Chiro District, West Hararghe Zone of Oromia Regional State of Ethiopia. It is found at location between 09°03'04"-9°07'20"N latitude and 40°52'42"-40°51'28 "E longitude. It is situated in the Eastern part of Ethiopia at a distance of 326 km from Addis Ababa; on the asphalt road that leads to Harar town. In the current base map of the town, it covered a total area of 31 square kilometers (i.e., 3100 hectares of land). The town is elongated to a north-south direction and a short breadth of east-west expansion which made the town to have a linear shape. The town has common boundary with surrounding rural villages some of which are currently administered under Chiro Town Administration. The town is located to the southeast of Miesso, north of Kuni and Bedessa, northwest of Arbereketi, and west of Hirna towns. According to the report of the Central Statistics Agency of Ethiopia (CSA, 2007) the estimated total population of the Chiro town at 2020 is about 80,873 and according to the data taken currently from the Chiro town municipality shows the current population of the town is 86,472.

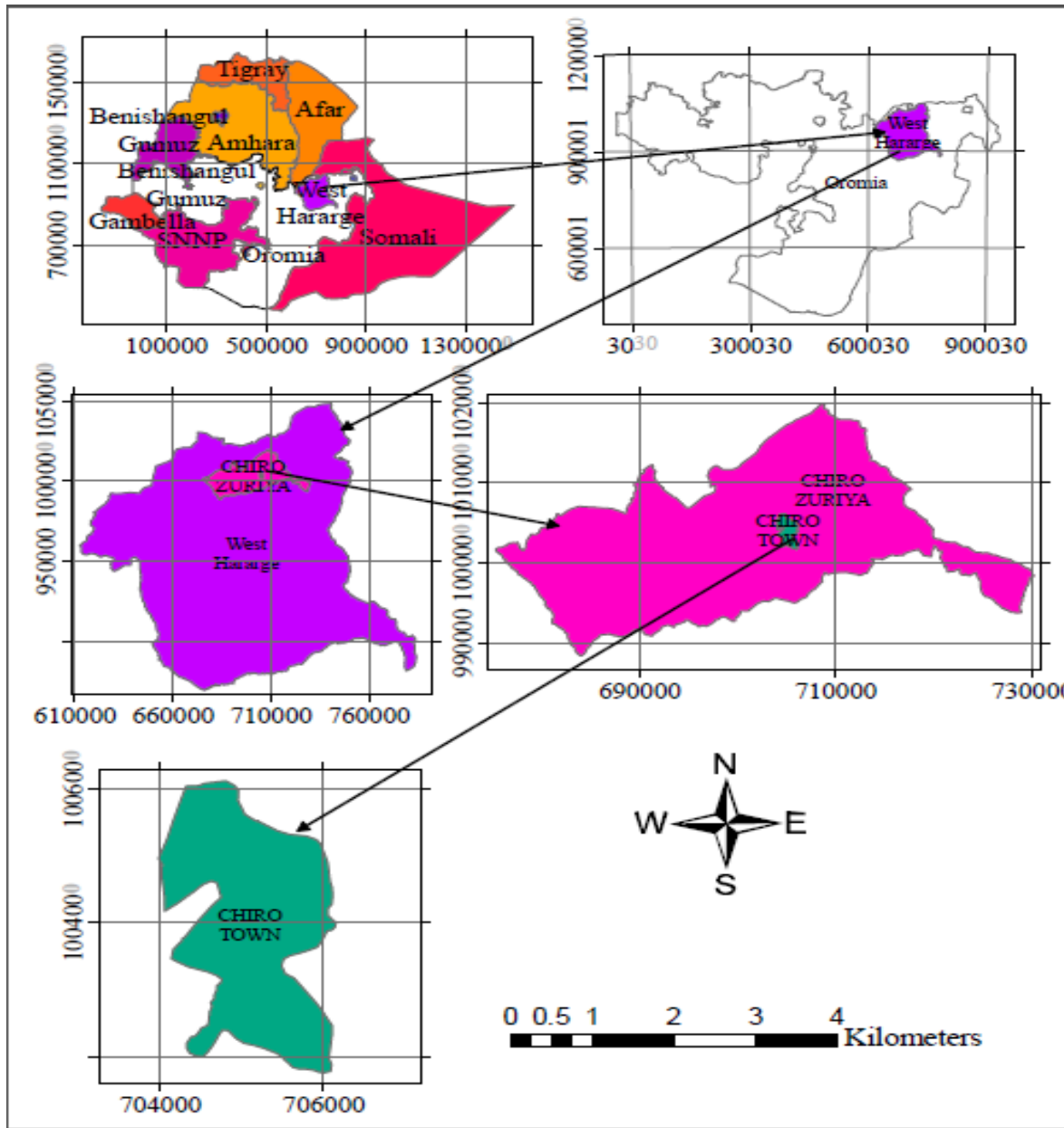
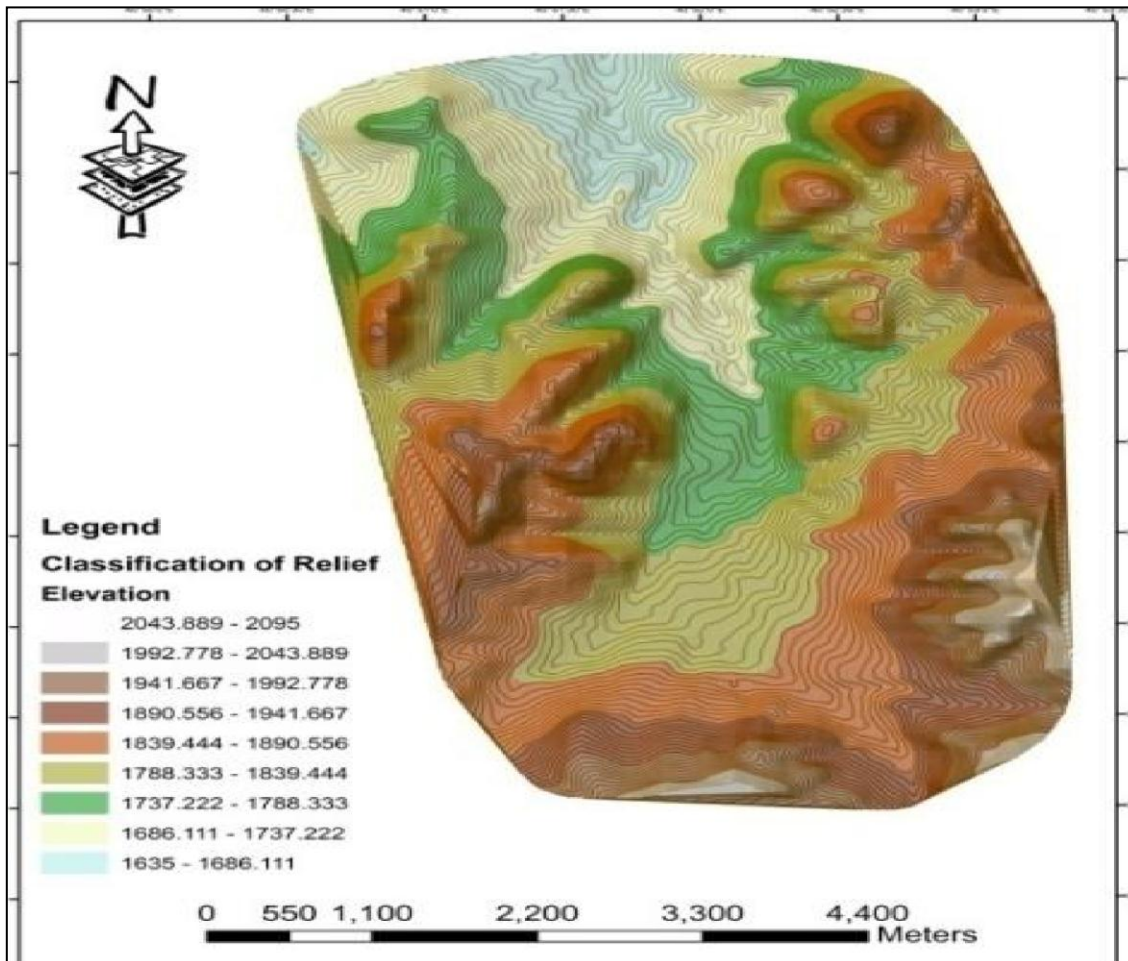


Figure 3.1 Location Map of the study area

### 3.1.1. Topography and Climatic Conditions of the area

The topography of the area can be characterized by the presence of chain of mountains and hills giving rise to high sloppy surfaces with some local flat land. The town is also characterized by vigorous types of topography with elevation difference ranges from 1635m to 2098m meters above sea level and high elevation values are observed in the upstream of the town of the South-East and low at North-west parts of the catchment or the lowlands are situated at the opposite periphery of the highest

elevation catchment North-west parts of the town, stream or the source of town water distribution system originate from Eastern parts of the catchment and the town is situated at an average elevation of 1867m above sea level and also average annual temperature range in between 15 °C to 25 °C.



*Figure 3.2 Contour Lines Showing Land Features of Chiro Town*

### 3.1.2. Regional geology

Regionally the area is characterized by quaternary volcanic terrains. Those quaternary volcanic rocks mainly comprise Plateau basalts (alkaline basalts and trachyte). The area also characterized by flat topography and number of escarpments (cliffs) that forming chain of mountains. In general the area has variety of thickness including the whole succession of volcanic rocks resting unconformable on the Sedimentary successions (Geological Map of Ethiopia, 1996). Geologically speaking

Chiro is located in Eastern Margin of the rift valley system. A topographic map of the area shows that Chiro Town is surrounded by basaltic and trachyte hills and ridges. Geologically the Chiro area is part of the central Ethiopia plateau, which is formed from different volcanic rock succession collectively called the trap series. Around Chiro town the trap series is composed of two geological units: older and younger units of rocks separated from each other by disconformities. The older rock units known as the Ashanghi-group: which consisted of rocks mainly originated from fissure eruption, which are mainly amygdaloidal basalts with rare sedimentary interactions, inter bedded tuffs and agglomerates here this group is found directly overlying the Mesozoic sediments. Alaje formation is found around the surrounding hills of the study area.

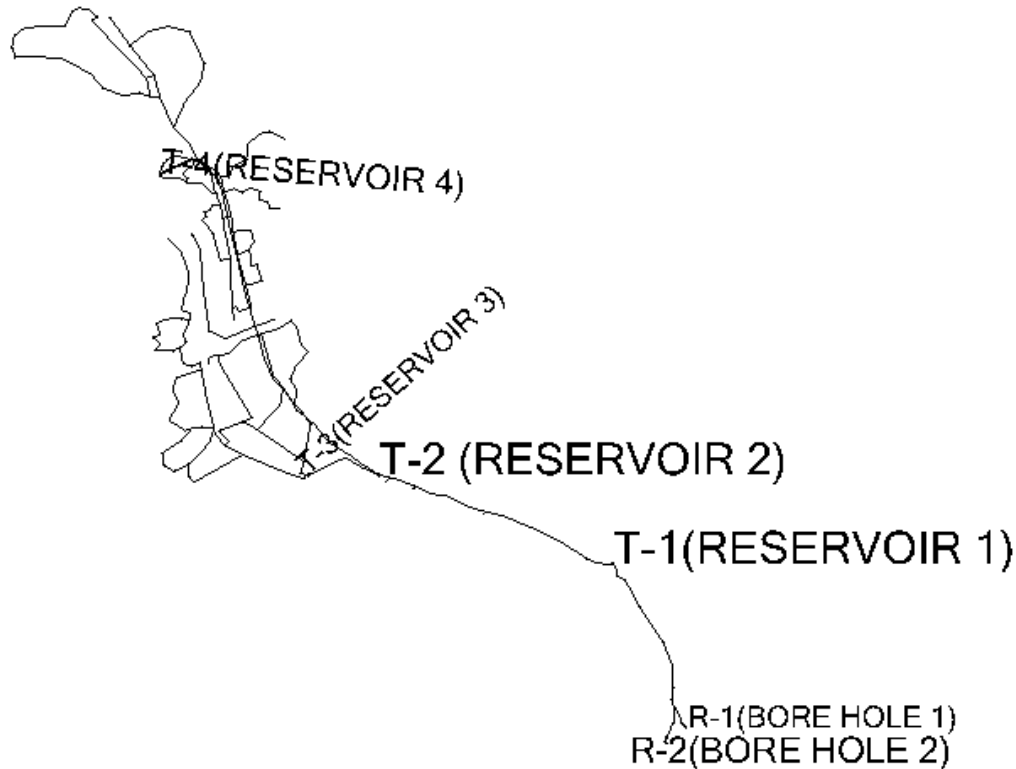
### 3.1.3 Existing Water Supply System Description

As per information obtained from Chiro town water service office, the design report was Designed by Share Company and constructed by Ansif Construction in 2006. Currently, house holders collect their total water needs from this water supply system and using directly through private connections and public taps.

There are four tanks (T) in the system

*Table 13.1 Tank data*

S/No	Description of the items	Types of tanks	Location			Tank Capacity (m <sup>3</sup> )	Purposes (Used)
			X	Y	Z		
1	T_1	Surface Concrete type	710010	1001209	2260	50	Pressure break
2	T_2	Surface Concrete type	706984	1002179	1938	500	Distribution reservoir
3	T_3	Surface Concrete type	706094	1002169	1875	200	Service Reservoir
4	T_4	Surface Concrete type	704310	1006036	1818	500	Service Reservoir



*Figure 3.3 Existing Chiro town water supply distribution system*

### **3.1.4 Components of water supply system**

The source water was delivered/pumped simultaneously in to the distribution network and service reservoirs from the ground through the two wells via 200mm DCI, (250mm, 300mm, 200mm, 150mm) uPVC, (100mm, 80mm, 50mm) HDPE, and (50mm, 40mm) GI pipe to attain the end users/consumers. From two wells, water pumped to the pressure break (25m<sup>3</sup>) and from pressure break provide water to the distribution tank (RC reservoir 500m<sup>3</sup>) by means of gravity. Then from distribution tank (reservoir), flow water to the two RC service tanks (two RC service reservoirs) (200m<sup>3</sup> and 500m<sup>3</sup>) to attain the end users via distribution pipe line and service connection line.

## **3.2. Materials**

### **3.2.1 Sources of data**

The source/basis of data for this thesis was involved both primary and secondary data. For this study, the primary data were obtained from trench or pit excavation along laid pipe where frequently pipe failures/ burst occurs, pressure reading, elevation surveying, measuring of pipe cover and pipe buried depth and by made of discussion with plumber who was present during the town water distribution system was done. While, secondary data were collected from different literature reviews, existing town (Chiro town) water distribution system or as built drawing of the Chiro Town water distribution network system, the town water supply service office existing documents (types of pipe and pipe diameter), Master plan of the Chiro town, pipe installation year, well completion report and pipe withdrawal for pipe repair/replacement reported papers or pipe burst history.

### **3.2.2 Equipment/tools used**

GPS instrument was used to collect the required elevation data along the laid pipe of main points. Water Pressure gauge instrument was used to measure pressure in the system at selected points or junctions. Meter is an instrument used to measure pipe cover depth and pipe buried depth at selected or frequently pipe burst was appeared and stop watch was used to measure the velocity appeared in the distribution system and also shovel and pick axe were used to pick up excavated soil and dig the soil respectively.

### **3.2.3 Hydraulic Model: Water GEMS**

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

calculate pipe flow and water pressure analysis, water quality simulation/ model, asset management (asset renewal or renovation/repair).

### **3.2.4 Addition 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, pipe cover depth and total pipe buried depth.

### **3.3. Methods**

Methods to follow for executed this thesis is first identify pipe burst history from Chiro town water supply utility. Based on the situation of pipe failure/burst throughout the system, estimate pipe failure causes considering physical factor (pipe size, pipe materials and pipe age), environmental factor/pipe installation condition (pipe bedding and backfill, trench excavation or pipe buried depth and pipe cover, soil type) and hydraulic factor (internal water pressure, transient pressure and flow velocity). Having estimated pipe failure causes, collect different data with respect to each factors from different sources of data (secondary/primary). Following the data collection, organize and analyzing data with respect to the situation of the pipe failure. For environmental factor, first identify which area under frequently bursting pipe and types of pipe with its sizes. Then pit (trench excavate) to measure the total pipe buried depth, pipe cover and soil type/structural type at these area and compare with standard. For physical factor, first identify types of pipe found in distribution and its diameters and pipe age. For hydraulic factor, based on the existing base map of the town water distribution network system Auto CAD to Water GEMS software and compute the system. Form compute/running the network identify pressure with respect of pipe size and nominal pressure of the pipes at area under frequently bursting pipe. Compare existing internal water pressure with standard pressure and nominal pressure of laid pipe. Then, identify whether environmental, physical and hydraulic factor is the main causes of pipe bursting or not in the system having calibration and validation works and finally, conclusion and recommendation works at the end.

### 3.4 Water loss

The water production and consumption of the Chiro town water supply service are assessed based on one year's record. The total water production of the one year recorded data taken from the water production record and time of pumping hour's document at each of the boreholes at the site and water consumption or billed water from office (Chiro town water supply Utility) to determine the water losses due to the pipe failures/bursts.

The total annual water produced and the water billed that was aggregated from the individual customer meter readings were used to quantify the total water loss for the town or used as an input for the water loss analysis. In this paper the water loss is calculated from the water production and consumption data of one year. As (Sharma, 2008) the total water loss is calculated as:-

$$\text{Total water loss(\%)} = \frac{\text{Total water production} - \text{Total water billed}}{\text{Total water production}} * 100\%$$

$$\text{Total Water loss(\%)} = \frac{903182 - 597805}{903182} * 100$$

Total water loss = 33.81%, in 2020

Table 3.2 Monthly Total Water Production, Consumption and Loss in Chiro

No.	Type	Jan.	Feb.	Mar	Apr.	Ma.	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec	Ave.	Tot al
1	production water (m)	5240	6252	7701	6106	7519	6841	113667	6862	6263	5885	7495	127879	75265.	903182
2	consumption (m)	4981	50,8	41,4	49,6	50,3	62,3	6022	5092	4738	4206	6084	5094	51,4	597805
3	loss water (m)	2,58	11,6	35,5	11,4	24,8	6,01	53,4	7,69	15,2	6,79	14,1	76,8	23,7	285377

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4	wallos ters in%	4. 94	18 .6	46 .2	18 .7	33 .0	8. 79	47 .0	26 .8	24 .3	28 .5	18 .8	60 .1	27 .6	% 3 3
---	--------------------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	-------------

Source: Chiro Town water supply utility

### 3.5 Pipe condition assessment

A condition assessment is a process to evaluate the pipe situations in the water distribution system. These situations can be analyzed based on the three factors (hydraulic, physical and environmental/Pipe installation condition). Based on the situations, collect different data (both secondary data and primary data) and analysis it. For determination of pipe failure in the system, develop the water supply distribution layout from base map (Auto CAD) of existing Chiro town water distribution line by using water GEMS software and enter the elementary data into the developed layout and running a developed system in order to compute pressures at each nodes and velocities in the pipes from existing data. Select location under frequently pipe failures along the pipe layout and measuring pressures and velocities in these locations and also compare with the output of the simulated model (layout). Measures of pipe buried depth and pipe cover depth by using pit (trench excavation works) at where pipe frequently under bursting and compare with the normal/standard depth of pipe laid under normal conditions and under carries. Then, calibration work by varying of parameters (pipe roughness coefficient) and variables (pipe diameters, pipe trench excavation depth) and compare output pressures with allowable pressures and velocities and also validation works to determine whether the hydraulic, environmental or physical are the causes of a pipe failure or not.

Based on the situations of a pipe failure (break/burst) in Chiro Town water supply distribution system, there is a different factors will be considered, such factors are illustrated in the following in the table 3.3

*Table 3.3 Estimated pipe failure factors for Chiro Town water supply distribution system*

Considered a Pipe failure ( break/burst) factors appeared in Chiro Town water supply distribution
--

system		
<b>1) Physical</b>	<b>2) Environmental (Pipe installation condition)</b>	<b>3) Operational/hydraulically</b>
a) Types of material	a) Pipe bedding	a) Internal water pressure
b) Pipe age	b) Pipe cover and backfill	b) Transient pressure (water hammer)
c) Pipe diameter	c) Buried depth of pipe	c) Flow velocity
	D) Soil types	

## 1) Physical factors

### A) Types of materials

Any water supply distribution system is constructed from different pipe materials which is made from different types such as metal pipes, Cement pipes and plastic pipes and pipes made from different materials fail in different ways (Wood Andrew and Barbara Lence, 2006). Chiro town water supply distribution network system contains different types of pipes such as DCI, uPVC, HDPE and GI. Generally, the system covered by DCI (6.33%), uPVC (36.67%) HDPE (52.5%) and also GI (4.5%) pipe (Chiro Town water supply utility, 2016).

### B) Pipe age (Year of Installation)

Pipe age is one of the factor that contribute pipe break/burst rate in water supply distribution system. Age is an indications of the length of time that a pipe has been in operation and exposed to the surrounding environment with in a both internal and external loading. In Chiro town water distribution network system pipe laid from 2013 to 2015. These are illustrated as the following table below:

*Table 3.4 pipe age (Year of installation)*

Types of pipe and its diameters			Year of installation		
Types of pipe	Diameter (mm)	Length (m)	2013	2014	2015
DCI	200	759	✓		
	250	2492		✓	
	300	290		✓	
uPVC	250	7924			
	300	2834		✓	
	200	3211		✓	
	150	5266		✓	
HDPE	100	8528			✓
	80	7056			✓
	50	12482			✓
GI	50	3071			✓
	40	745			✓

Source: Chiro town water supply office, 2016 and direct interview of plumbers that were present in that time (during a pipe layout was executed).

### **C) Pipe diameters**

Pipe diameter is one of the physical factor which is affecting pipe failure rates. Based on the size of the pipe, different studies had been concluded that small pipe diameter is more susceptible for break/burst rate than the large diameter (e.g. Boxall et al., 2007). This is due to the pipe wall thickness. Meaning the pipe wall thickness of a large diameter is greater than the small pipe diameter which can easily susceptible for failure (break/burst) due to internal/external factors. In Chiro town water supply distribution network system contains, different types of pipes with different pipe diameters such as DCI (300mm, 250mm, 200mm), uPVC (300mm, 250mm, 200mm, 150mm), HDPE (100mm, 80mm, 50mm) and GI (50mm, 40mm) (Chiro Town water supply office,2016).

*Table 3.5 Summary of pipe in distribution system with respect to the locations*

Item	Pipe	Diameter(mm)	Length (m)	Locations
------	------	--------------	------------	-----------

No.	Material			
1	GI	40	2463.89	Distribution line
		50		
2	HDPE	50	28745.33	Distribution line
		80		
		100		
3	uPVC	150	20077.93	Distribution line
		200		Transmission line
		250		
		300		
4	DCI	200	3465.86	Transmission line and distribution line
		250		
		300		
Sum			54753	

Source: Chiro town as built drawing and field measures

## 2) Pipe installation conditions

### a) Pipe bedding

Pipe bedding support is an important part of a pipeline installation and the pipe must be placed in a proper bedding. Ideally, a pipe should be supported uniformly over its entire length or free from irregularity surface. Pipe bedding with selected materials (free-flowing materials) is the main parties to prevent pipe from break/burst especially for plastic pipes which laid in rock area. In Chiro Town water supply distribution system, more than 85% of pipe laid was plastic pipes. Even though it was more plastic pipe laid, there is no pipe bidding practice throughout the system. But, the area pipe laid was mixed boulder stone with soil. So, the procedure to detect whether pipe bedding was exist or not in the system (Chiro Town water supply distribution system) is direct measuring on the sites. First to identify the locations (places) where pipe frequently bursting occurred and then test it by trench (pit) excavation work along the pipe laid.

### b) Pipe cover and backfill

Pipe cover and backfills are the most parts for resist incoming pressure which in the surrounding of the laid water supply pipe. Pipe cover advantages to prevent pipe from incoming vertical loading and also against vertical deformations of pipes. Backfill used to support against lateral deformations of pipe. The procedure to detect whether the laid pipes of a system (Chiro Town water supply distribution system) has a pipe cover or not with selected materials are the following. First to identify the locations of pipe break/burst frequently throughout the system. Then test it by trench (pit) excavation work along the pipe laid and measure it by meter and observe around pipe whether backfilled has selected materials or not. As standard, different types of distribution mains have different pipe cover depths in different situations (under types of soil types and pipe laid through a different external loads applied on the pipes).

*Table 3.6 Depth of cover for different pipes laid in underground for urban water supply distribution network*

Types of materials	Types of water distribution pipes	Normal depth cover (cm)	In rocky area Minimum Cover depth (cm)	Under carriage way (cm)
DCI	Main line/Transmission	80	60	100
GI	Main line/Transmission	80	60	100
uPVC	Main line/Transmission	90	60	100

*Source: Ministry of water resource, urban water supply design criteria, January 31, 2006*

### **c) Buried depth of pipe**

The total pipe buried depth is the sum of the diameter of laid pipe and pipe cover which laid over a pipe. Good pipeline installation, provides sufficient total buried depth. The procedure to measure the total pipe buried depth is to identify the locations of pipe break/burst frequently throughout the system. Then test it by trench (pit) excavation work along the pipe laid and measure it by meter (Pipe cover + pipe diameter). Generally, to minimize pipe failures, pipe cover depth can be varied from a minimum of

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0.6 m (under foot path/normal conditions) to a normal conditions of 0.9 m (Under carriage way or normal traffic road) either transmission or distribution lines (the republic of Uganda ministry of water and environment, water supply design manual second edition, 2013) and 0.6m to 1m (Ministry of water resource, urban water supply design criteria, January 31, 2006). Nine points (locations) were selected for detect the pipe failure from the system due to frequently burst of pipe appeared at this location than the others points along distribution system (Chiro Town water supply distribution system). At these points to identify pipe cover, total buried depth of pipe, pipe bedding, by trench excavation or pit test along the laid pipe as shown in the table 3.7 below.

*Table 3.7 pipe buried, cover depth, and bedding situation measured on the site*

S/No	Types of materials	Internal Diameter(mm)	Pipe nominal pressure (bar)	Year of installation	Label(Burst)	Location			Situation or at pipe burst place		
						X	Y	Z(m)	Cover(m)	Total depth(m)	Bedding
1	uPVC	250	10	2013	B1	710813	998995	2230	0.4	0.68	No
2	uPVC	250	10	2013	B2	707607	1001901	2255	1.06	1.33	No
3	uPVC	300	10	2013	B3	708425	1001753	1921	0.85	1.18	No
4	uPVC	150	10	2014	B4	704997	1002171	1811	0.80	1	No
5	HDPE	100	16	2015	B5	705223	1005748	1715	0.5	0.65	No
6	HDPE	100	16	2015	B6	705525	1005728	1774	0.42	0.52	No
7	HDPE	100	16	2014	B7	704591	1006126	1771	0.3	0.4	No
8	HDPE	80	16	2015	B8	704100	1007195	1685	0.62	0.70	No
9	HDPE	50	16	2015	B9	705109	1006046	1648	0.65	0.72	No

Source: Field measures

Some points (places) were taken from the town water distribution system where the pipe burst was not appear till this field measured(18/04/2020) start from installation years. These points were selected having same types of pipes with the same diameters like place where pipe burst was happened for plastic pipes and also different types of

pipes at where pipe does not under failures, but at different points or locations as shown in the table 3.8

*Table 3.8 pipe buried, cover depth, and bedding situation measured on the site*

S/No	Types of materials	Internal Diameter(mm)	Pipe nominal pressure (bar)	Year of installation	Not burst occurs	Location			Situation or at pipe burst place		
						X	Y	Z(m)	Cover(m)	Total depth(m)	Bedding
1	DCI	200	16	2013	J_3	710696	999198	2208	0.8	1.08	No
2	uPVC	250	10	2013	J_10	70999	1000905	2263	1.04	1.31	No
3	uPVC	300	16	2013	J_15	708670	1001546	2023	0.87	1.2	No
4	uPVC	150	16	2014	J_86	704757	1003162	1784	0.85	1.05	No
5	DCI	250	16	2014	J_36	705424	1003888	1754	0.68	0.83	No
6	HDPE	100	16	2014	J_154	704939	1005562	1726	0.71	0.81	No
7	HDPE	50	16	2015	J_160	704945	1004851	1775	0.8	0.9	No
8	GI	50	16	2015	J_210	704985	1004437	1771	0.6	0.65	No
9	GI	40	16	2015	J_221	705281	1003827	1756	0.61	0.68	No

Source: Field measures

### 3) Hydraulic conditions

#### a) Internal water pressure

Internal water pressure is one of the problem that leads to a pipe burst especially plastic pipe if greater than pipe nominal pressure. According to FDRE, MoWR, 2006, the standard pressure for water supply system shall be designed to maintain a normal condition and maximum pressure in water distribution system is 60m and 70m respectively. In order to predict pipe failure in the system (Chiro town water supply distribution system), first collect different data (secondary and primary data) and data analysis then develop the pipe distribution layout from existing base map of the Chiro town water supply distribution system and enter the elementary data into a developed layout. Then, running the system to predict whether the internal water pressure is the cause of a pipe failure or not for the same nominated pipes and the same locations for

investigations of physical and environmental factors. Having different/varying parameters (Pipe diameters, pipe types and roughness coefficient due to the age of the pipe) calibration work and compare with measures of pressures on the field at nominated points and also compare with allowable pressures (60-70m) and finally, validation applied.

*Table 3.9 operating pressure in water distribution network*

Status	Normal Conditions	Exceptional Conditions
Minimum	15 m water head	10 m water head
Maximum	60 m water head	70 m water head

*Source: Ministry of water resource, urban water supply design criteria, January 31, 2006*

#### **b) Transient pressure (water hammer)**

Transient pressure (water hammer) is one of the problems of pipe burst, when there is a disturbance of flow water (either an acceleration or retardation) in the pipe was appeared. This phenomenon leads to rise the pressure in the pipe and due to an increasing of a pressure, pipe failures will be appeared in the system. This consequences rise from different reasons such as closing or opening a valve, due to different fittings on the laid pipe, starting or stopping of a pump or when operating conditions in the pipeline change. In Chiro town water supply distribution system, shortage of pump occurred frequently and also pipe failure was appeared at near to the wells at the joint of the pipes which rises from the two wells. The power system is used in the system is grid system. On this site the Electric power was not constant or not continuous power which is suddenly switch off when the pump is running and also current fluctuations. So, the pump suddenly stopped. This leads to the disturbance of flow water in the pipe line.

### **c) Flow velocity**

Velocity is one of the effect on the pressures in the water supply distribution system, which leads to the disturbance of flow water the in the pipe if greater than allowable/ permissible velocity. In water supply distribution system, acceptable velocity ranges 0.6 to 1.5m/s and exceptional up to 3m/s. If greater than 3m/s, not acceptable velocity due to the disturbance of the flow water in the pipe which may be leads to a water hammer in the pipe and pipe failures occurred. Generally, if the velocity appear in the water supply distribution network system is greater than 3m/s, the water hammer will develop, this leads to pipe burst (KL&KIJLC.WALSKI, T.M. Analysis of Water Distribution, 1971).

### **3.6 Pipe burst history**

Pipe breaks/burst history is one of the main factor to detect the sequences of pipe burst was registered in a water supply distribution system or Pipe failures (burst) history is one of the indications of pipe risk assessment for prediction of the pipe failure causes (Physical factors, Environmental factors and Operation/Hydraulic conditions) either separate or the combinations of them could be affected a pipe in the system frequently at fixed point. In Chiro Town water supply distribution system, there is no arranged registered pipe burst history of a distribution system on the shelf. Unfortunately, sparsely (not well arraigned/inconsistent) data about the pipe burst with burst location along the line and also date of drawn out the pipe from store was available on the hand of the store keeper person for pipe replacement at some places from 2015 to 2020. These data can be illustrated as the following table below:

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Table 3.9 Pipe burst per year

S/No	Label (burst)	Pipe burst per year					
		2015	2016	2017	2018	2019	2020
1	B1 (J_4)	3times(19/2,02/9/,26/11/2015)	2times (14/3/,27/8/2016)	1time (19/11/2017)		2times(04/1/,11/4/2019)	
2	B2 (J_B2)		1time (21/6/2016)		1time(02/9/2018)		
3	B3 (J_20)	2times(05/7/,4/13/2015)	1time (17/9/2016)			3time (29/4/,06/8/,13/11/2019)	1time (02/2/2020)
4	B4 (J_B4)		3times (16/5/,21/7/,09/9/2016)			2times (26/3/2019 & 15/8/2019)	1time (19/2/2020)
5	B5(J_169)	1time (03/5/2015)		4times (11/3/,27/10/,24/11,01/13/2017)	1time (16/8/2018)	3times (24/6/2019, 10/8/2019 & 07/12/2019)	-
6	B6(J_172)	-	2times (13/2/2016 & 02/11/2016)	-	1time (21/4/2018)	1time (18/9/2019)	1time (27/2/2020)

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7	B7 (J_125)			1time(22/4/ 2017)		2times (10/7/2019 & 14/9/2019)	
8	B8 (J_186)			1time (11/11/201 7)	3times (18/6/,0 6/8/,27/ 8/2018)		1time (05/1/2020)
9	B9 (J_177)	1time (25/12/ 2015)		2times (10/9/,12/1 2/2017)		2times (19/4/2019 & 12/7/2019)	
10	J_8		1time(6/ 4/2016)				
11	J_130	1time(3 /3/2015 )					
12	J_19	1time(4 /13/015 )					
13	J_207		1time(17 /10/016)				
14	J_188				1time(2 9/5/018)		
15	J_191		1time(10 /11/2016 )				
16	J_167		1time(29 /6/2016)				

Source: Chiro Town water supply authority office, 2015-2020, from store keeper recorded data for pipe replacement.

From above table, nine pipe burst locations were selected based on the occurrence of pipe burst for at least two times of pipe failure was appeared at specific (the same) point than the other points. These points were illustrated in the following table.

*Table 3.10 Selections of pipe burst history for analysis of pipe burst causes*

Label at Pipe burst	Pipe Burst per year						Average pipe burst occurs per year
	2015	2016	2017	2018	2019	2020	
B1	3	2	1		2		1.33
B2		1		1			0.33
B3	2	1			3	1	1.17
B4		3			2	1	1
B5	1		4	1	3		1.5
B6		2		1	1	1	0.83
B7			1		2		0.5
B8			1	3		1	0.83
B9	1		2		2	1	1

Source: Chiro Town water supply office, 2015-2020, from store keeper recorded data for pipe replacement.

### **3.7 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 decreases as pipe age

increase, so, C-factor is depending on pipe materials and its age; this effect can be shown in table 3.11 and 3.12 below (Tomas, et al., 2003).

According to Chiro town water service office, DCI, uPVC, HDPE and GI pipe laid in the water distribution network was not served more than 7years.

*Table 3.11: Roughness coefficient, C- factor for different pipe material, continued*

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

LAMONT (1981)

(Source: Tomas, et al., 2003)

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Table 3.12: Roughness coefficient, C-factor for different pipe material

Type of Pipe	C-factor Values for Discrete Pipe Diameters					
	1.0 in. (2.5 cm)	3.0 in. (7.5 cm)	6.0 in. (15.2 cm)	12 in. (30 cm)	24 in. (61 cm)	48 in. (122 cm)
Uncoated cast iron - smooth and new		121	125	130	132	134
Coated cast iron - smooth and new		129	133	138	140	141
30 years old						
Trend 1 - slight attack		100	106	112	117	120
Trend 2 - moderate attack		83	90	97	102	107
Trend 3 - appreciable attack		59	70	78	83	89
Trend 4 - severe attack		41	50	58	66	73
60 years old						
Trend 1 - slight attack		90	97	102	107	112
Trend 2 - moderate attack		69	79	85	92	96
Trend 3 - appreciable attack		49	58	66	72	78
Trend 4 - severe attack		30	39	48	56	62
100 years old						
Trend 1 - slight attack		81	89	95	100	104
Trend 2 - moderate attack		61	70	78	83	89
Trend 3 - appreciable attack		40	49	57	64	71
Trend 4 - severe attack		21	30	39	46	54
Miscellaneous						
Newly scraped mains		109	116	121	125	127
Newly brushed mains		97	104	108	112	115
Coated spur iron - smooth and new		137	142	145	148	148
Old - take as coated cast iron of same age						
Galvanized iron - smooth and new	120	129	133			
Wrought iron - smooth and new	129	137	142			
Coated steel - smooth and new	129	137	142	145	148	148
Uncoated steel - smooth and new	134	142	145	147	150	150

(Source: Tomas, et al., 2003)

### **3.8 Network Simulation**

To build and simulate the hydraulic model, Bentley water GEMS, graphical editor water distribution modeling software was used. The water distribution network map was obtained from the town water service office, which was drawn in water CAD drawing pane with physical observation. The network simulation was taken steady state by consideration of C-factors variations and pipe material diameter variations.

### **3.9 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 at place were frequently pipe burst appeared throughout the system.

## **CHAPTER FOUR**

### **4. Results and Discussions**

#### **4.1 Existing water supply system**

The source of water supply for the Chiro town is groundwater. The system contains two deep wells (two boreholes) which was constructed (drilled) in 2013 and the system constructed from different types of pipe materials. Such as DCI, uPVC, HDPE and GI pipes and the town water distribution length covered by more plastic pipes. But, more the geological area of the town is covered by rock area (mixed soil with stone boulders). Frequently pipe failure was happened throughout the system. Due to the failure (burst) of the pipes in the system, there is a shortage of water supply in the town.

#### **4.2 Elevation longitudinal profile of the major pipelines**

Longitudinal profile of a pipe lines show that the water distribution system convey water or draw from the water source to the water consumptions. In Chiro town water supply distribution system, convey water from the sources to the service reservoirs are illustrated on the following figures. This profile executed from main pipe line or transmission line and the locations of different appurtenances of layout along the line.

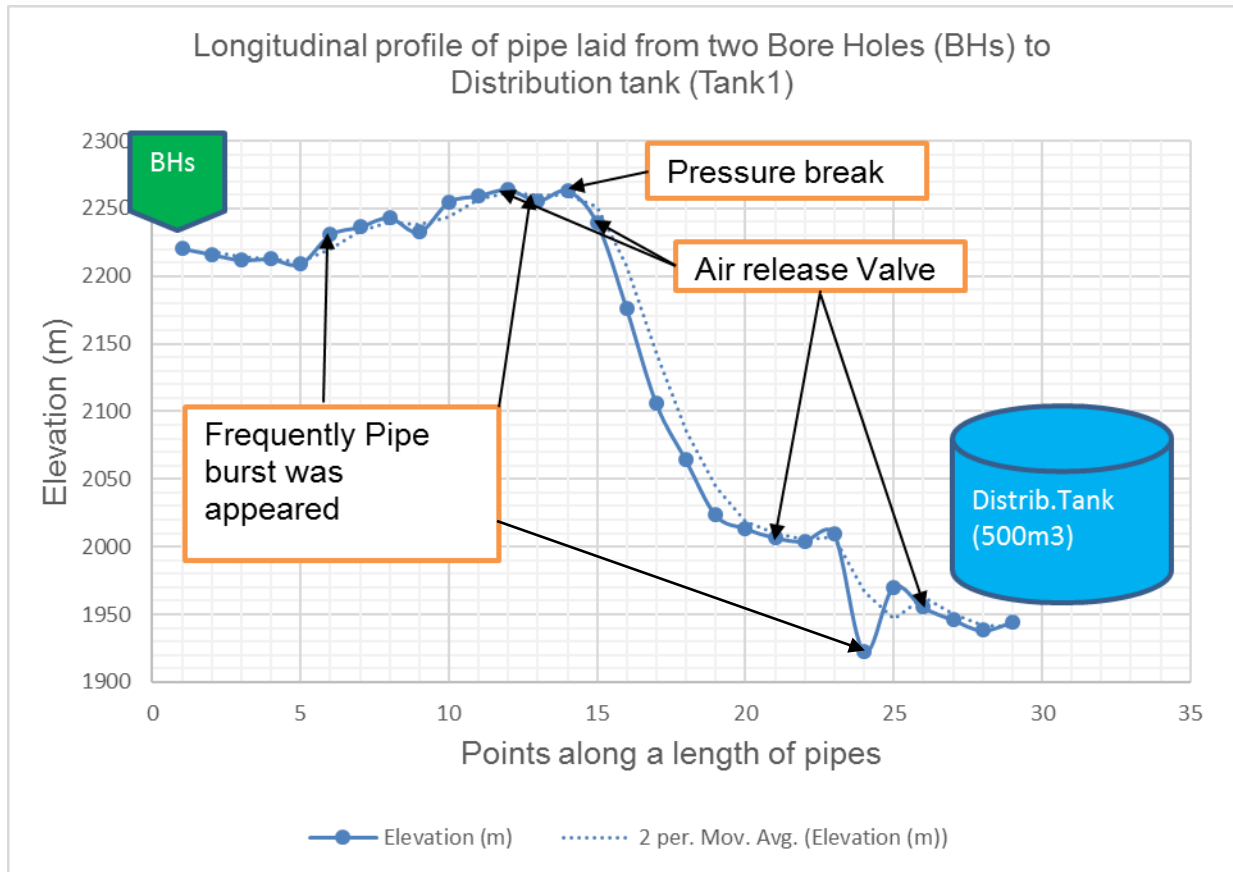


Figure 4.2.1. Elevation longitudinal profile of transmission line from Bore holes to Dist. tank

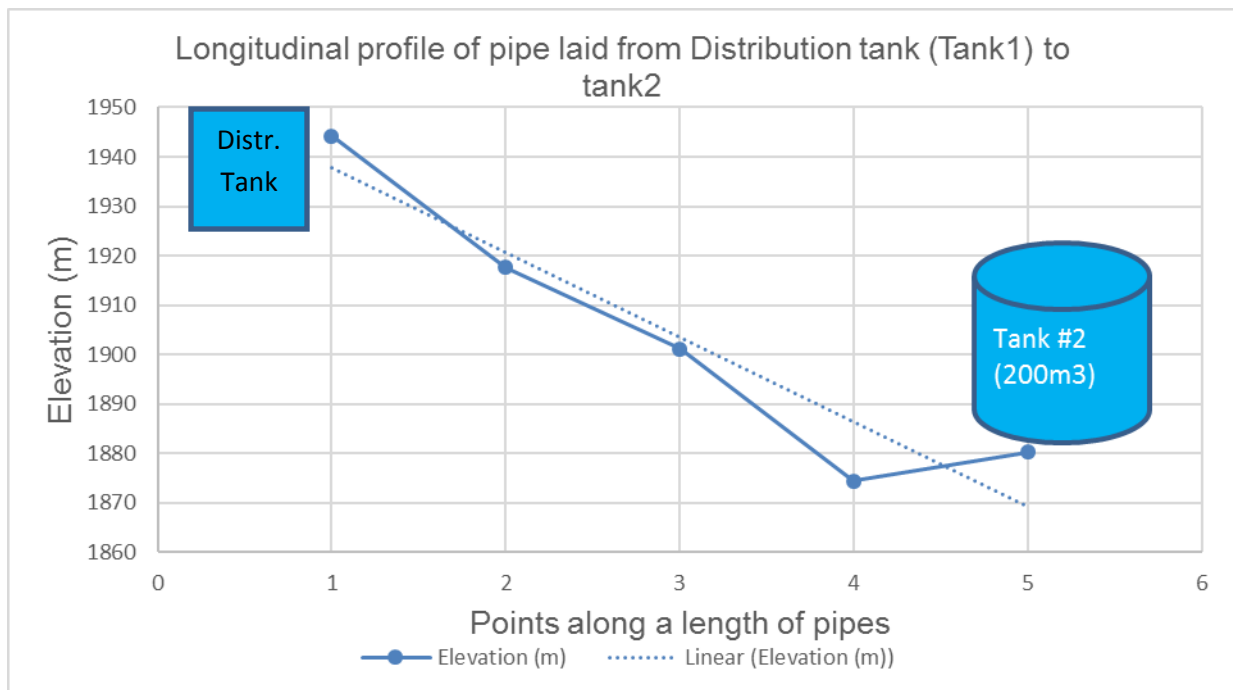


Figure 4.2.2. Elevation longitudinal profile of pipe line from distribution tank to service reservoir (Tank #2)

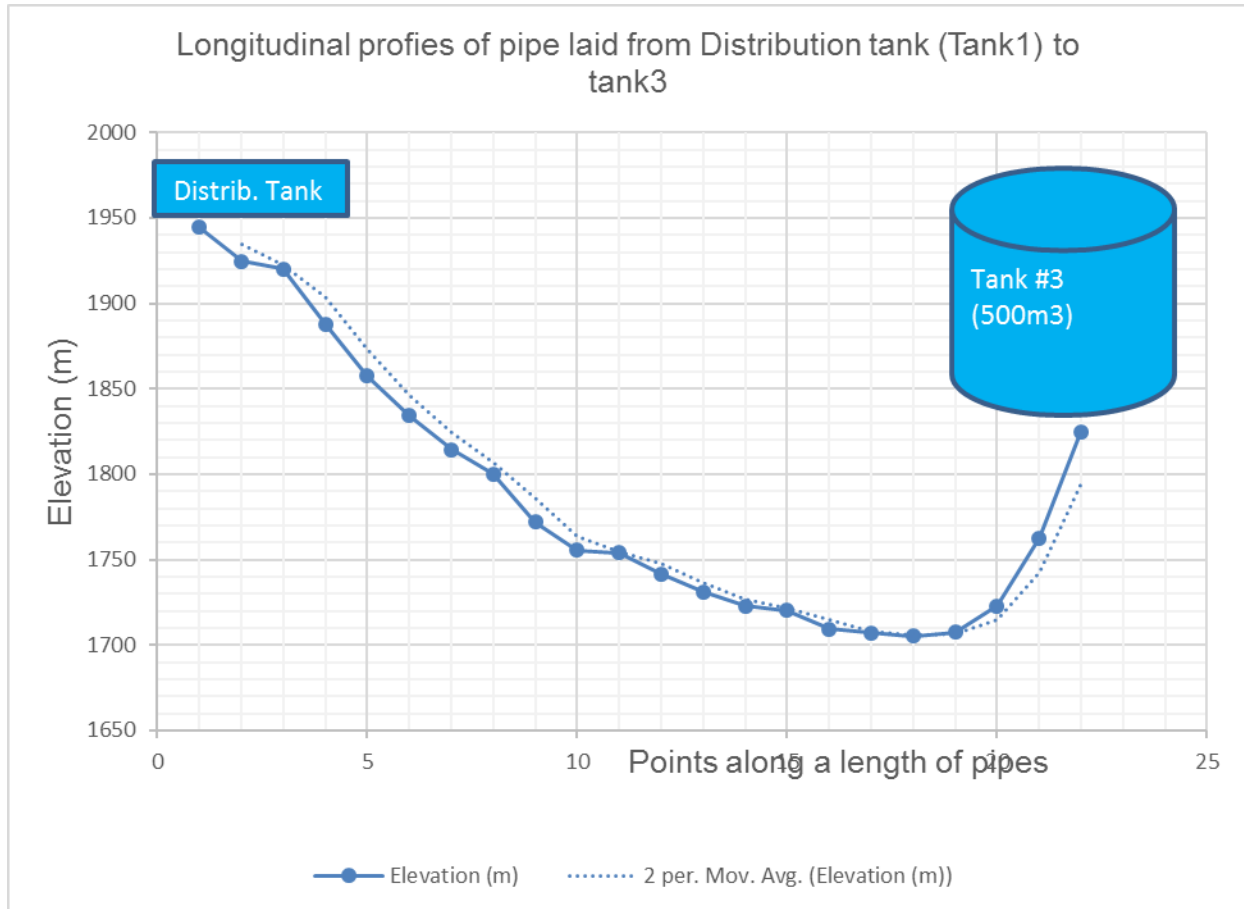


Figure 4.2.3. Elevation longitudinal profile of pipe line from distribution tank to service reservoir (Tank #3)

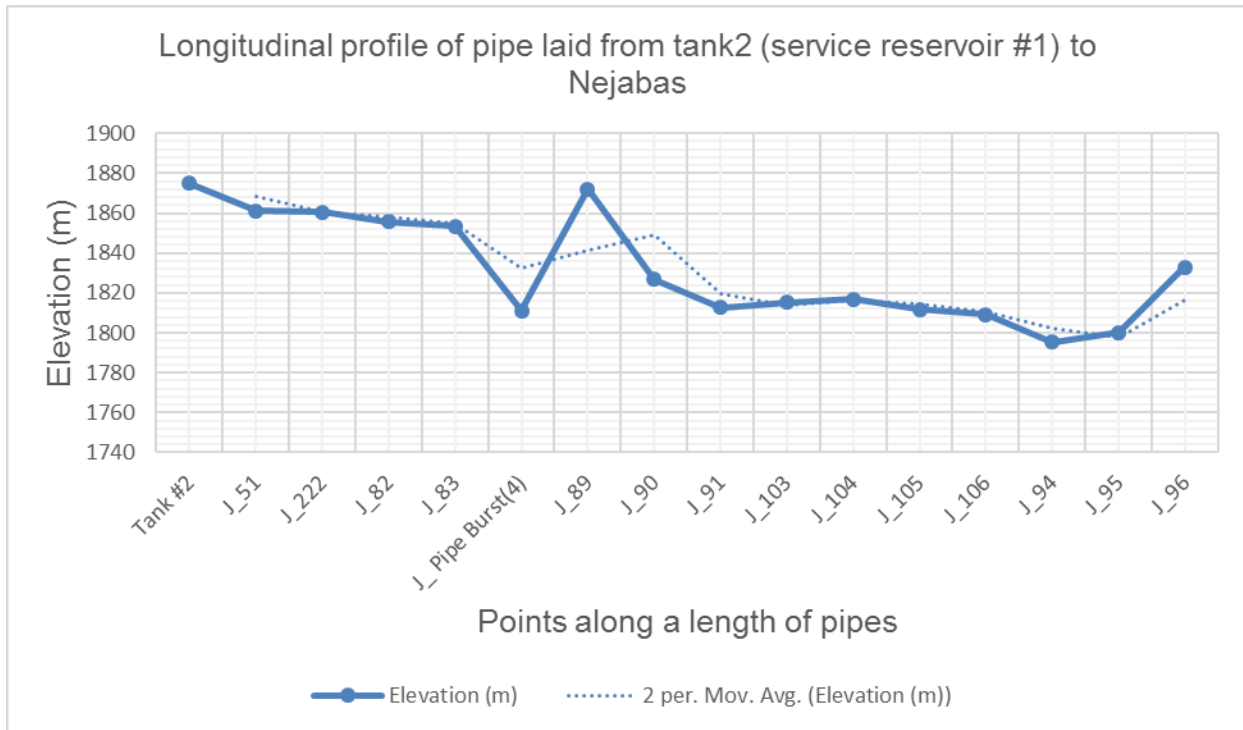


Figure 4.2.4. Elevation longitudinal profile of pipe line from service reservoir (Tank #2) to Nejabas

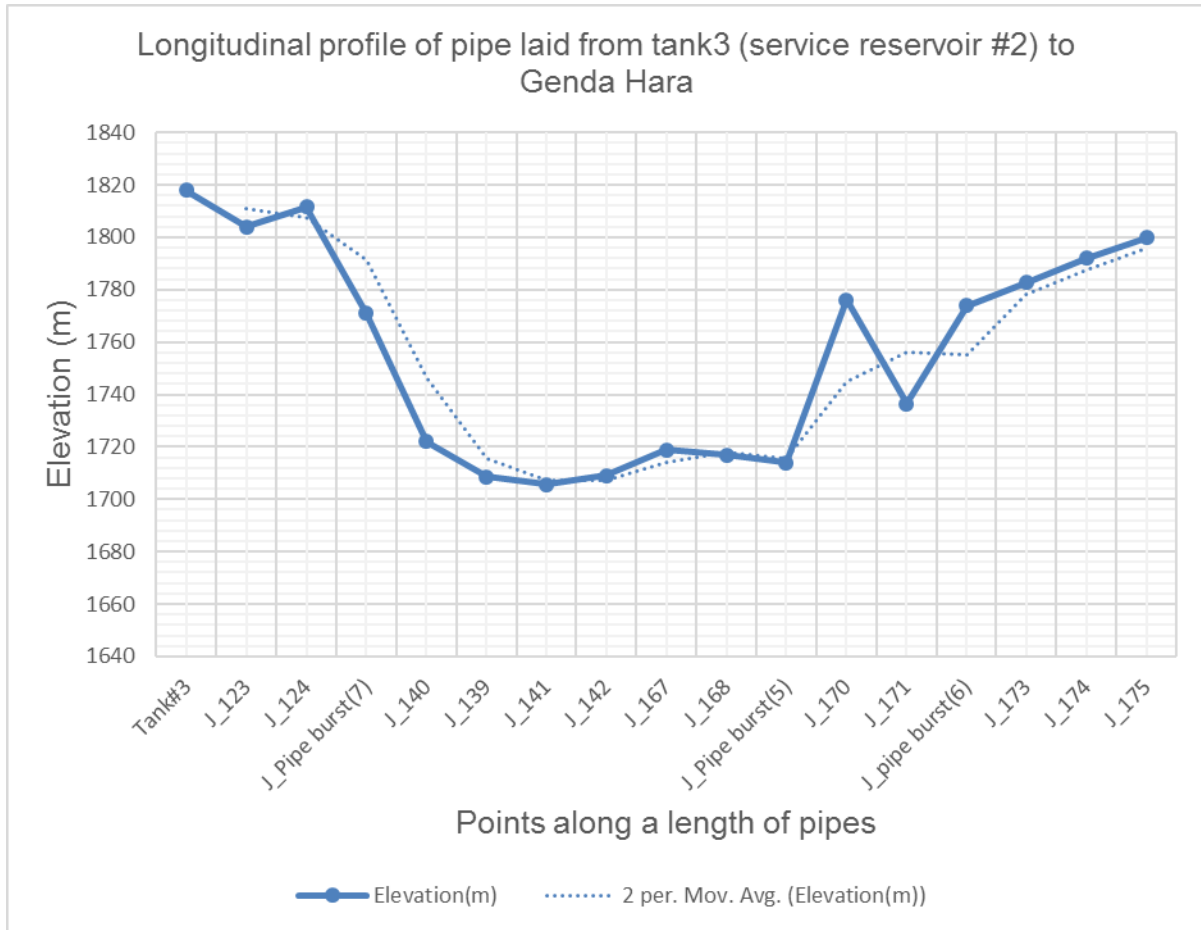


Figure 4.2.5. Elevation longitudinal profile of pipe line from service reservoir (Tank #3) to Genda Hara

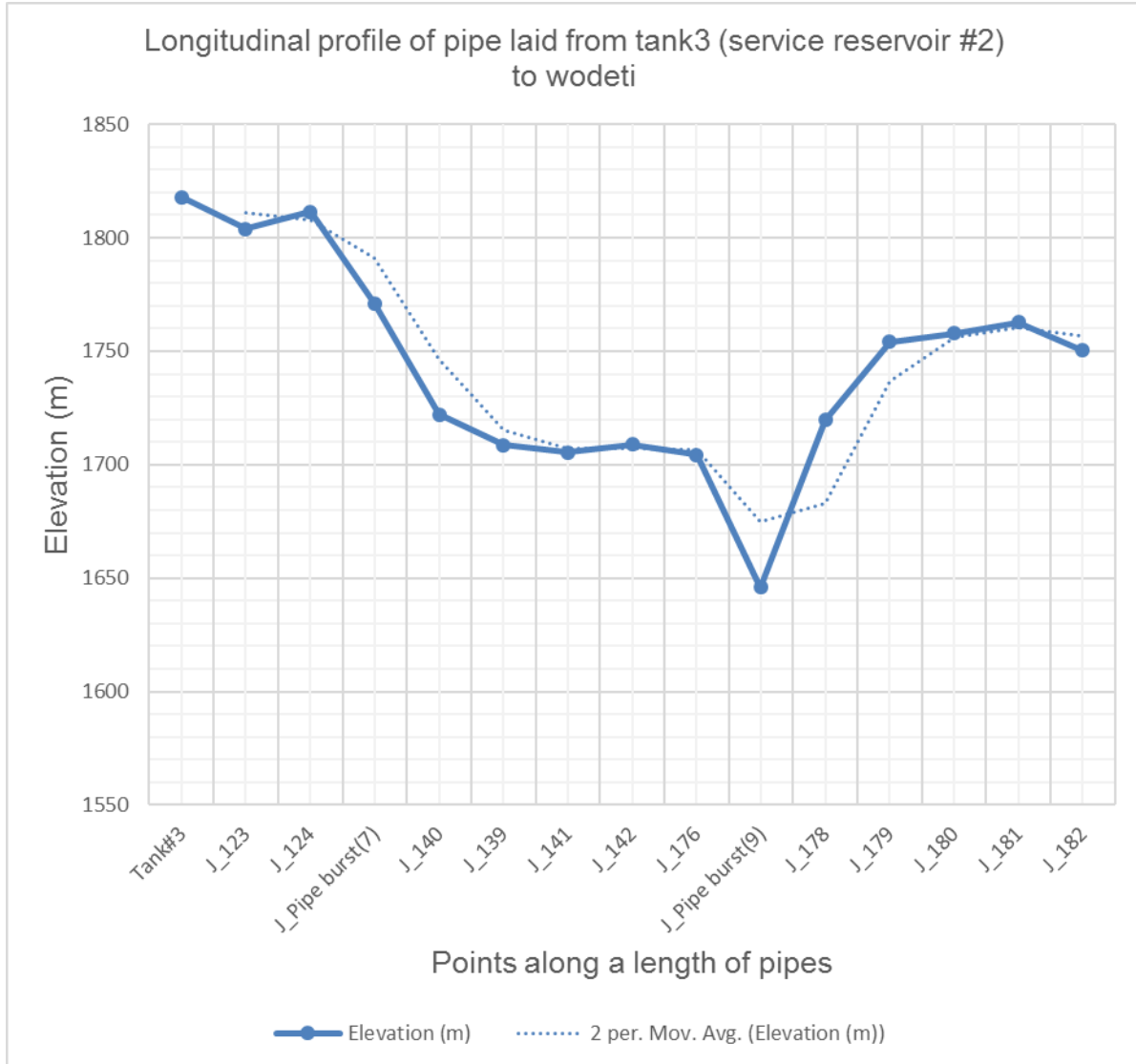


Figure 4.2.6. Elevation longitudinal profile of pipe line from service reservoir (Tank #3) to Wodeti

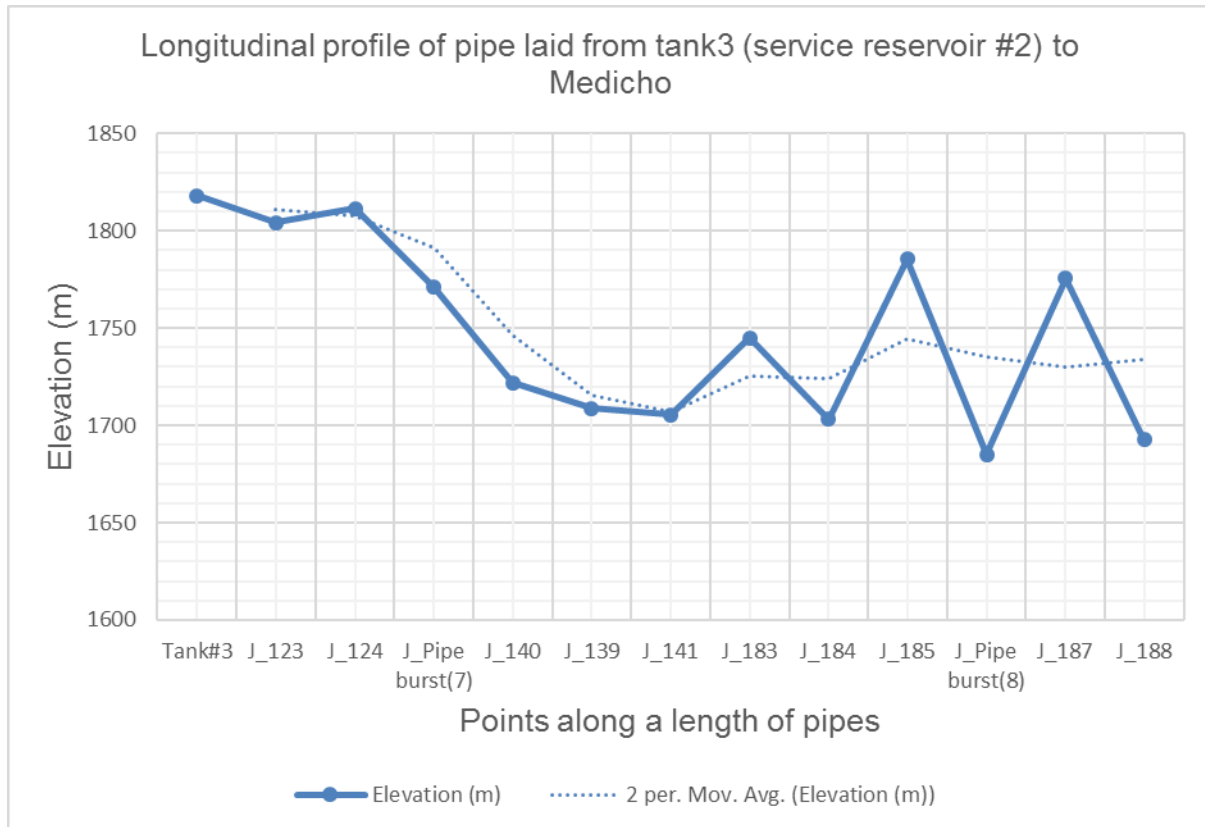


Figure 4.2.7. Elevation longitudinal profile of pipe line from service reservoir (Tank #3) to Medicho

### 4.3 Pressure distribution profiles in the major pipeline

Pressure distribution profiles from source to the targeted points (end uses) to detect whether the hydraulic condition is the cause of pipe burst or not by comparing allowable pressure (working pressures in the water supply distribution system) and nominal pressure of the pipe at frequently pipe burst was appeared and discuss on it. These situations (draw profiles) can be executed by dividing layout the system. Such as draw the internal water pressure verse points from two wells (bore holes) (2220m & 2215m) to pressure break at elevation 2260m, from pressure break to distribution tank (Tank1) at elevation 1938m, from Tank 1 to Tank 2 at elevation 1875m (Service Reservoir) and Tank 3 at elevation 1818m (Service Reservoir) and also from Tank 2 and Tank 3 to users as shown in the following figures.

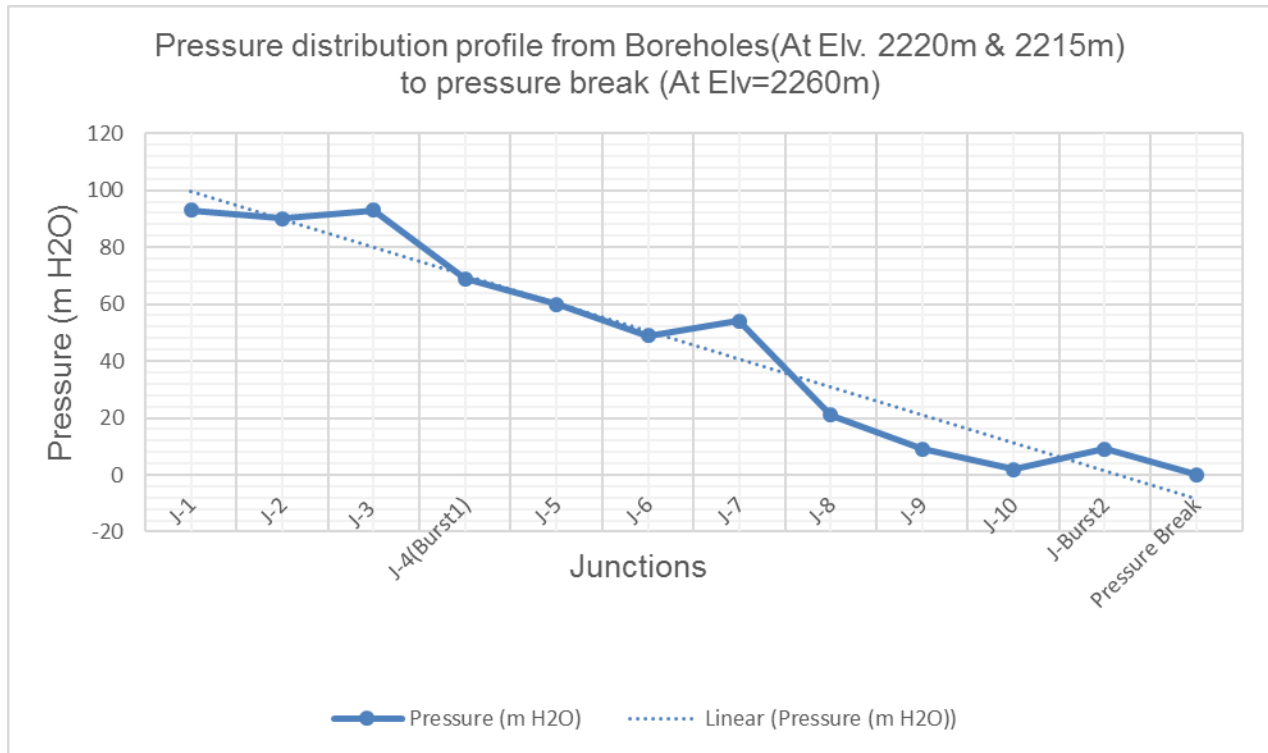
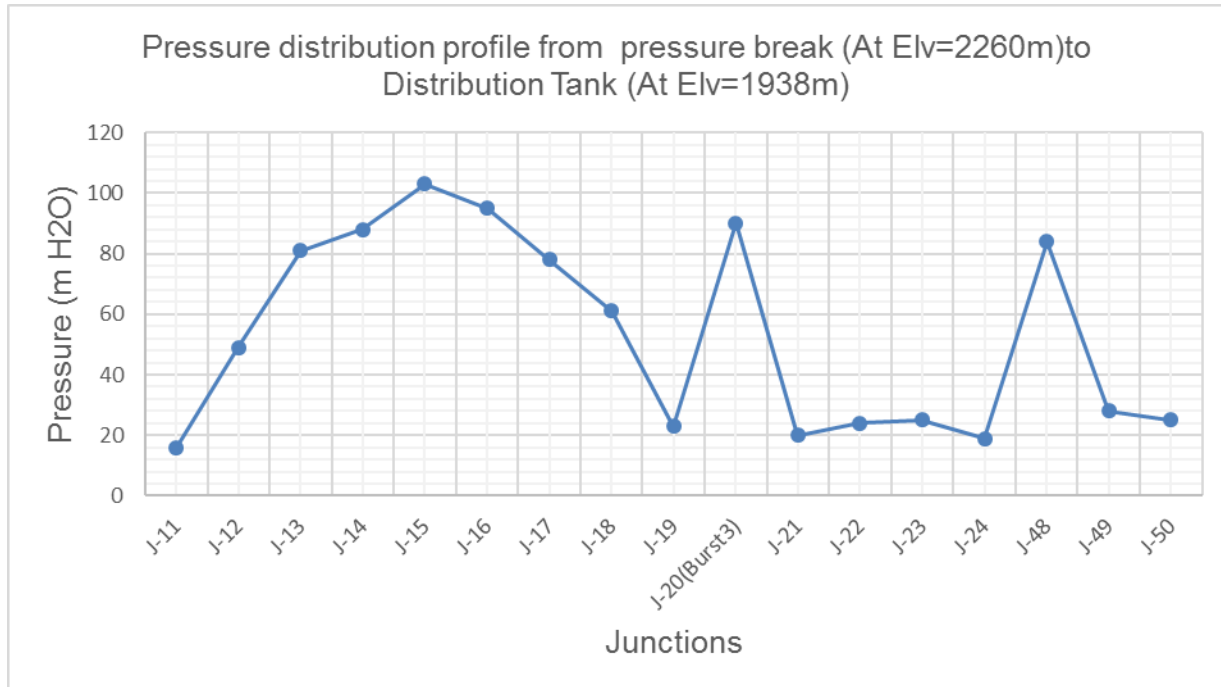


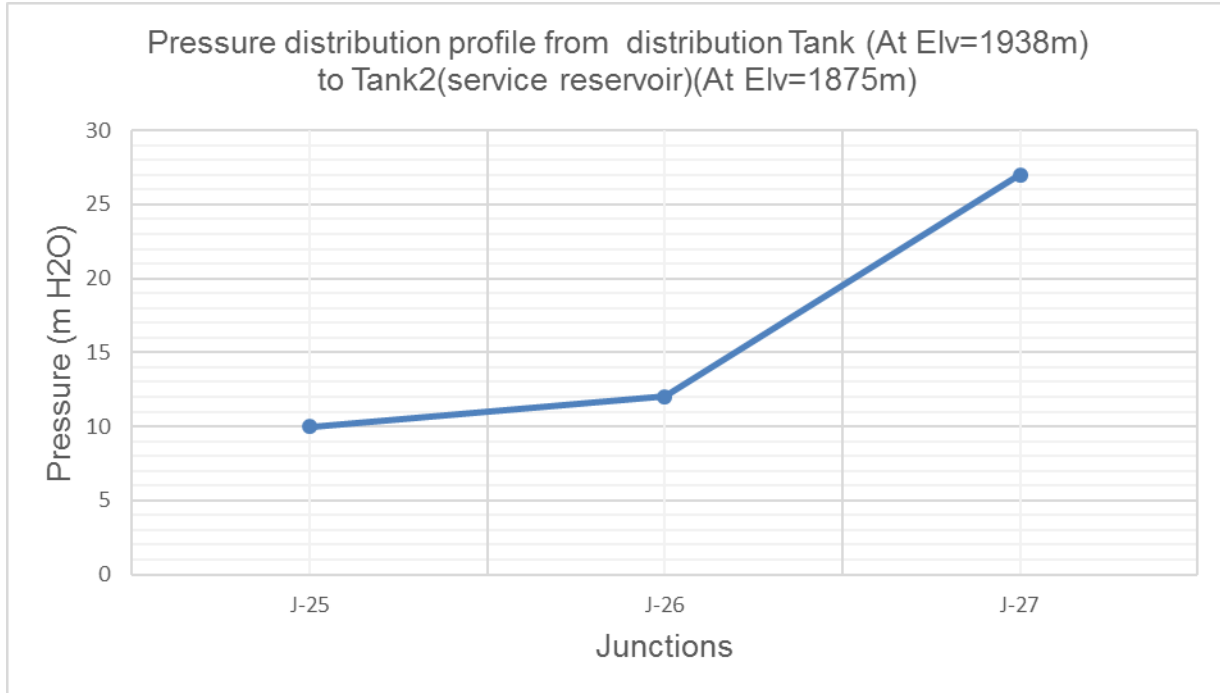
Figure 4.3.1 Pressure distribution profile from two wells to pressure break

Frequently bursting of uPVC pipe (250mm diameter, PN10) was appeared between two wells and pressure break at two places along the laid pipes. The pressure appeared at these places were 69 m and 9m at junction 4 (B1) and junction B2 respectively. But, when compared to the normal operating pressure(60m-70m) both pressures happens are less than the operating pressures (69m<70m & 9m <60m).



*Figure 4.3.2 Pressure distribution profile from pressure break to Tank 1*

Frequently bursting of uPVC pipe (300mm diameter, PN10) was appeared between pressure break and distribution tank (tank 1). The pressure appeared at this place was 90 m at junction 20 (B3) and when compared to allowable operating pressure, the pressure event was greater than the operating pressure (90m>70m). So, hydraulic condition could be one of the factors which leads to a pipe burst at this junction.



*Figure 4.3.3 Pressure distribution profile from Tank1 to Tank 2*

All pipe laid between these two points distribution tank (tank 1) and service reservoir (tank 2) are uPVC pipe (250mm diameter, PN16). At this area there is no pipe burst found from installed year to this day (15/01/2020) or has no pipe burst history and also low pressure appeared at these areas (i.e 10,12,27mH<sub>2</sub>O).

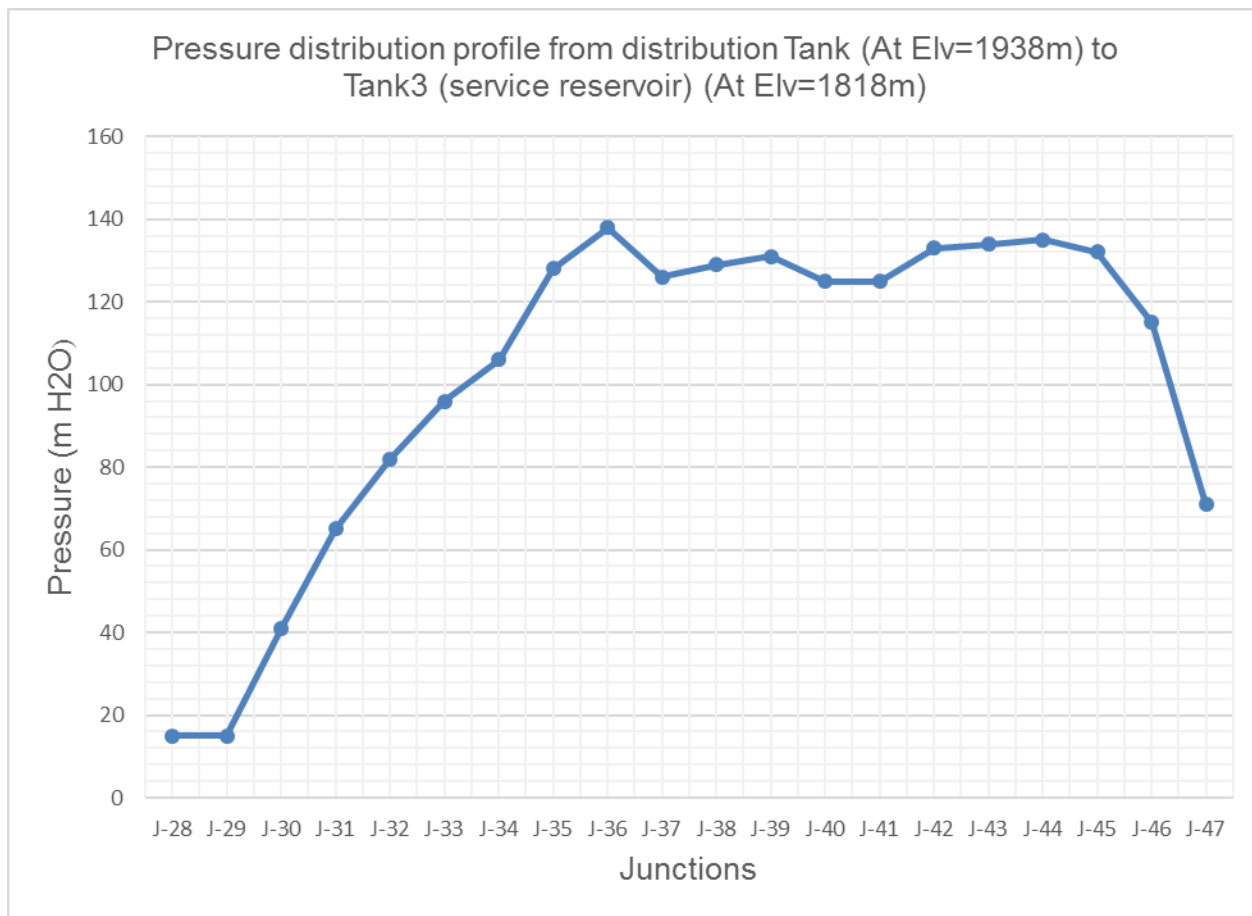


Figure 4.3.4 Pressure distribution profile from Tank1 to Tank 3

All pipe laid between these two distribution tank (tank 1) and service reservoir (tank 3) are DCI pipe (250mm diameter, PN16). At this area there is no pipe burst found from installed year to this day (15/01/2020) or has no pipe burst history.

Frequently bursting of uPVC pipe (150mm diameter, PN10) was appeared between Tank 2(service reservoir #1) and end points. The pressure appeared at this point is 66 m at junction B4 and when compared to the allowable pressure, the pressure event at this point is less than the allowable pressure (66m<70m) or lies between 60m and 70m. So, the pipe burst factor at this point is other factor than hydraulic condition.

Frequently bursting of HDPE pipes (100mm, 80mm &50mm diameters), were appeared between Tank 3(service reservoir #2) and end points at different places. The pressure appeared at these places are 101 m at junction-169 (B5), 40m at junction 172 (B6), 49m at junction 125 (B7), 122m at junction 186 (B8) and 169m at junction 177 (B9) and when compared to the allowable pressure, the pressure events at junction 169 (B5), junction

186 (B8) and junction 177 (B9) are greater than the allowable pressure (>70m). So, according to sufficient water pressure rule (rule of allowable pressure appear in water supply distribution system in different countries 60-70m), hydraulic condition is one of the factor which leads to the pipe burst factor at these locations (points). But not due to the PN of the pipe. According to the PN (nominal pressures of pipe) which means the resisting capacity of pipe can resist internal water pressure till the PN of the pipe and if coming pressure greater than the resting capacity of the pipe, pipe may be burst. At junction 172 (B6), junction 125 (B7) less than the allowable pressures (60m-70m). So, the pipe burst factor at these locations (points) were other factors than hydraulic condition.

#### **4.4 Pipe burst history**

As literature review for pipe failure rate analysis, the standard that pipe failure rate in cases of water supply main distribution lines are different with respect to the types of the lines such as in transmission line, distribution line and service connections. These situations were demonstrated based on the inconsistency of the system (water supply) to the consumers due to the pipe failure for all types of the pipe in nominated water supply distribution network. So, in case of transmission line pipe failure rates should not exceed 0.3 pipe failure/km/year, in case of distribution line pipe failure rates should not exceed 0.5 pipe failure/km/year and in case of service connection pipe failure rates should not exceed 0.1 pipe failure/km/year (Rak, J.R. 2007 & Kwietniewski, M. 2011). Generally, according to Kwietniewski, M. 2011, the average pipe failure rate in water supply distribution network values rise between  $0.1 \leq 0.5$  pipe failure/km/year. In Chiro Town water supply distribution system, there is a different pipe failures were appeared in the system at different locations and occurred in different types of pipes. These events are listed in the following table. And the pipe failure rate appeared in the transmission line >0.3 pipe failure/km/year. This situation show that the consistency of the water supply is less in the town due to the transmission line. These scenarios are illustrated on the table 4.4.1

Table 4.4.1 Pipe burst/km/year for particular nodes

Type of Pipe	Diameter(m)	PN(m)	pressure (mH <sub>2</sub> O) measured	pressure(mH <sub>2</sub> O)	Allowable Pressure (m)	Pipe burst/km/year	Maximum limit of pipe burst/km/year
B1(UPVC)	0.25	100	69	63	70	0.65	0.3
B2(UPVC)	0.25	100	9	27	70	0.16	0.3
B3(UPVC)	0.3	100	90	81	70	0.37	0.3
B4(UPVC)	0.15	100	66	74	70	1.03	0.5
B5(HDPE)	0.1	160	101	103	70	1.64	0.5
B6(HDPE)	0.1	160	40	42	70	0.91	0.5
B7(HDPE)	0.1	160	49	35	70	1.37	0.5
B8(HDPE)	0.08	160	122	115	70	0.83	0.5
B9(HDPE)	0.05	160	169	159	70	2.31	0.5

Sources: Chiro Town water supply office, 2015-2020, from store keeper recorded data for pipe replacement.

PN(m)	Simulated pressure (mH <sub>2</sub> O)	Measured pressure(mH <sub>2</sub> O)	Allowable pressure (m)
100	69	63	70
100	9	27	70
100	90	81	70
100	66	74	70
160	101	103	70
160	40	42	70
160	49	35	70
160	122	115	70
160	169	159	70

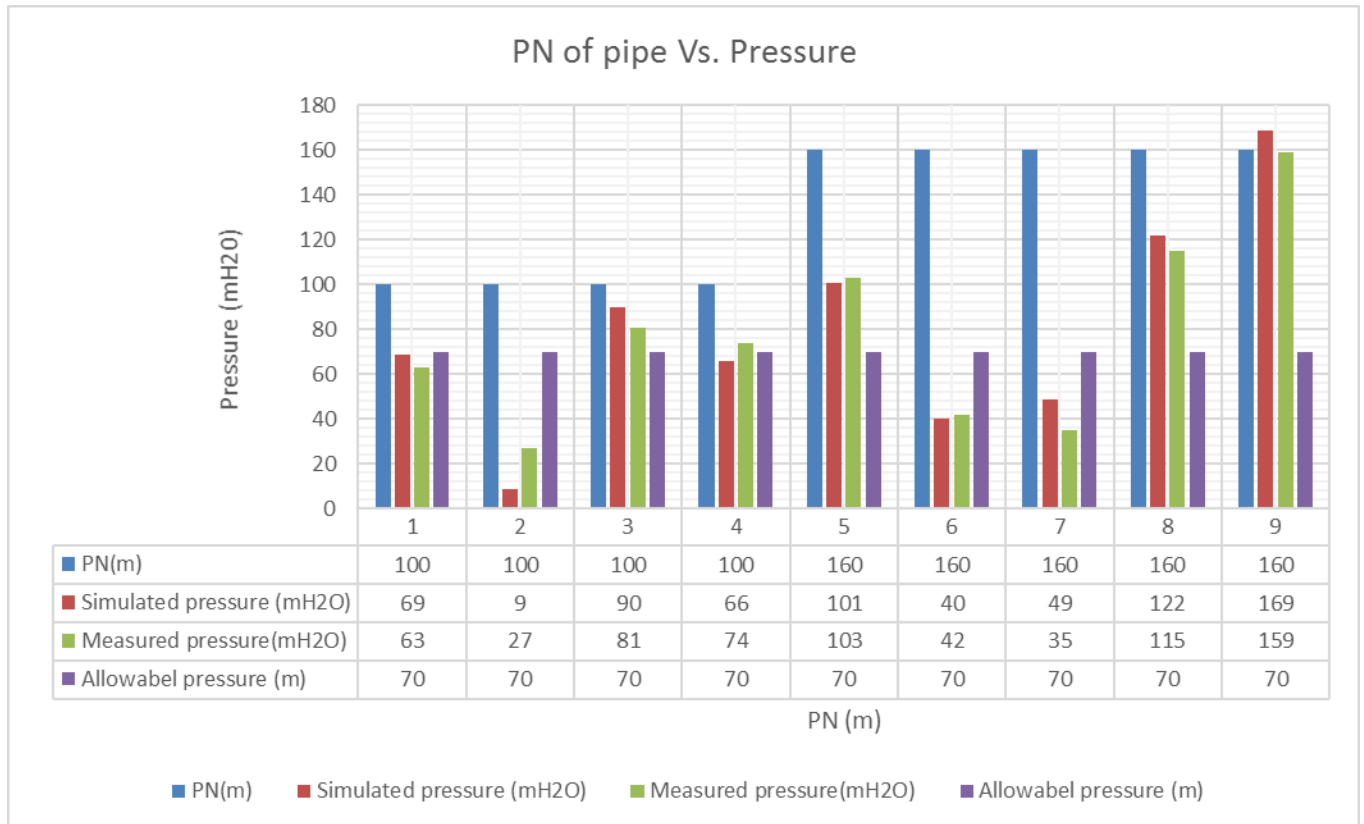


Figure 4.4.1 Pipe failure rate (pipe failure/km/year)

#### 4.5 Identify the causes of pipe failures (bursts) in the system

In Chiro town water supply distribution system, pipe failure appeared due to different factors. To distinguish these factors, consider three main factors (physical, Pipe installation conditions and hydraulic /operational factors) can be discussed as shown below:

##### 4.5.1 Physical factor

Causes of pipe burst investigate under this factor (physical factor), consider different parameters based on the conditions of the town (Chiro) water distribution system such as types of pipe materials, pipe age and pipe diameters.

##### 4.5.1.1 Types of pipe materials

Total water distribution length in the town is 54753m, with plastic pipe (uPVC and HDPE), metallic (GI) and DCI materials accounting for around 89.17, 4.5 and 6.33 percent of the total water distribution length, respectively. Pipe burst was happened in the plastic pipes than the others (DCI & GI pipes) throughout the system, due to the

poor installation practices during the construction phase (absence of pipe bedding and back fill with selected materials at rocky area and shallow pipe buried depth in the agricultural land due to more transmission lines passes through the farming land) and also used where high water pressure was appeared which is greater than allowable pressure. And also pipe burst was appeared in HDPE pipe due to poor installation practices (absence of pipe bedding and back fill with selected materials at rocky area) and pipe used at where high water pressure appeared. As pipe break/burst history recorded in Chiro town water supply utility office, there is no pipe failure was appeared in the parts of DCI and GI pipe network.

#### **4.4.1.2 Pipe age (Year of Installation)**

Pipe failure rate due to the pipe age is more exposed due to corrosion or weakness from the environment assembles with time and type of pipe material which can easily susceptible with different pipe failure (burst) mechanisms/factors with time. Plastic pipe (uPVC and HDPE) normally doesn't easily susceptible by corrosion and metallic pipe (GI) and DCI pipe may or may not easily susceptible by corrosion based on the quality of supplied water and types of soil surrounded the laid pipe. But, types of soil surrounded the laid pipe test is beyond this research. If supplied water has low PH, the water has acidic condition or high salt levels which can cause internal corrosions of the water pipe. As from well completion report of the two wells (bore holes) of Chiro town water supply distribution system as shown on **Appendix G**, PH of the water for both wells were PH=7.26. So, the water is almost neutral water that means it is not acidic water and it does not cause internal corrosions of the water pipes through the system and also the system does not such much time to exposed the environment (count long time). So, in Chiro town water supply distribution system pipe age was not closely relate to water pipe failure causes and also due to the pipe corrosion.

#### **4.5.1.3 Pipe diameters**

In Chiro town water supply distribution network system contains different types of pipes with different pipe diameters such as DCI (300mm, 250mm and 200mm), uPVC (300mm, 250mm, 200mm, 150mm), HDPE (100mm, 80mm, 50mm) and GI (50mm, 40mm). In case of uPVC pipe, more pipe burst was appeared in lower or small diameters than the larger diameters at different places/locations due to environmental

factors and hydraulic conditions. But, in case of HDPE pipe burst, more appeared in higher or larger diameters than the small diameters at different places/locations due to environmental factors with geological formation of the area pipe laid through it. In general condition, as diameter of the pipe increases pressure event in the pipe decreases and also velocity decreases.

#### **4.5.2 Environmental factors (pipe installation conditions)**

In Chiro town water supply distribution system, poor installation of pipe laid was happened throughout the system like absence of pipe bedding and backfill with selected materials mainly for plastic pipe (uPVC and HDPE) in rocky area, large stone where unfavorable area for plastic pipe laid and also shallow pipe cover depth or pipe buried depth in agricultural land due to the main pipe laid through the farming land. Some air release valve used in the system where located are not recommend area such as at steeply drop down slope (chute flow) for prevent the accumulated air bubbles in the pipe at four places. Since the transmission lines passes through a farmer land, the farmer demolished the man hole covers of the air release valves and fetch water at this points and also deliver (divert) water to agricultural lands to practice an illegal irrigation. During this situations practiced pipe failure was appeared at this location. The main pipe installation conditions considered in this paper is discussed as the following.

##### **4.5.2.1 Pipe bedding and backfill**

In Chiro town water supply distribution system, there is a poor pipe installation practice on a rocky area. Among these absence of pipe bedding and backfill with selected material is one which leads to a pipe burst. Such events were appeared at different locations along the pipe distribution line. Example at (X=705096, Y=1002477, Z=1811) on uPVC pipe (150mm diameter and PN10) due to poor installation practiced on a pipe line (no pipe bedding and backfill with selected materials). The situations of pipe burst at this locations, some formations of holes on a pipe laid as shown on the figure 4.4.1. And also pipe burst appeared on the HDPE pipe at location (X=704591, Y=1006126 and Z=1771m) on a distribution line (100mm diameter and PN16) as shown on the figure 4.4.2. So, absence of pipe bedding and backfill is one of the factor that leads to pipe burst in the system.

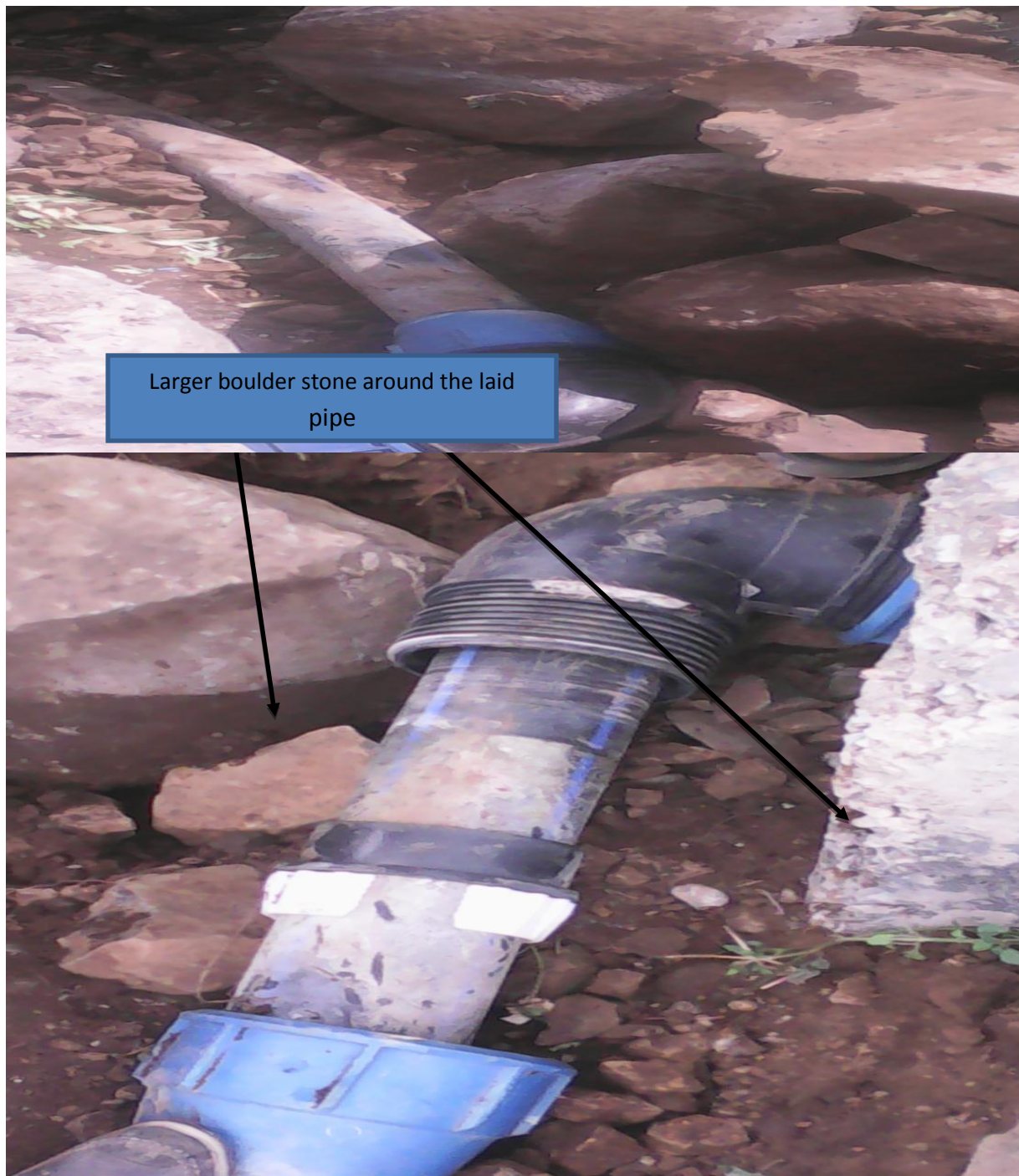


Source: field measure

*Figure 4.5.1 uPVC Pipe burst due to the absence of a pipe bedding and backfill with selected materials*

#### **4.4.2.2 Pipe cover and backfill**

Backfill provides the primary support against lateral pipe deformation. Pipe backfill /cover materials should be free from a large rocks and debris. According to the FDRE, MoWR,2006, urban water supply design criteria and ministry of water and environment of Uganda, 2013, the minimum of the pipe cover at rock area is 0.6m ( at under foot path or normal conditions) and 0.9m /1m (under carriage (traffic load) conditions) for every type of water supply pipe layout in the town. In Chiro town water supply distribution system, poor backfill/pipe cover practiced was one of the problem appeared in the system for pipe burst/break factor as shown on the figure 4.5.2. At this location or area the type of pipe laid was HDPE pipe (100mm diameter, PN16) and this pipe burst was found at the out let of the service reservoir two (Tank-3) at location (X=704591, Y=1006126 and Z=1771m) which was appeared frequently. At this point the pipe cover was 0.3m which is more less than the normal water pipe cover ( $0.3m < 0.6m$ ). Even though a present cover pipe, it is not selected material which prevent pipe from burst/break rates. It was large boulder stone laid over and around the pipe as a pipe cover or back fill. This leads to pipe burst due to external load was exerted on the laid pipe having internal water pressure exerted on the laid pipe.



Source: Field observation

*Figure 4.5.2 HDPE pipe burst due to poor installation condition*

#### **4.4.2.3 Buried depth of pipe**

Total pipe buried depth is one of the factor that contribute the pipe failures in this system. Since most transmission pipelines was laid in the agricultural land and having low pipe cover, example the pipe laid covered by small (shallow) depth (0.4m), suddenly the farmer was penetrated or burst/break the pipe during ploughing their land. Such example was as illustrated on the figure 4.5.3 at location (X=710813, Y=998995, Z=2230m) and type of pipe used was uPVC pipe (pipe diameter 250mm, PN10) at just the outlet of the junction of the two pipe lines which rise from two bore holes. The two lines come from its specified well was connected (combined) by fitting called Y. From history of running time of the two pumps from the two wells were usually at the same time in every days. So, at this point there is the disturbance of flow water occurs in the pipe and this point found just at the out let of the two combined lines which rise from the two wells. Due to the disturbance of water flow in the pipe, also disturb the base foundation of the pipe laid over because of the absence of proper pipe bedding. Unfortunately, the pipe laid at this area was uPVC pipe with no pipe bedding and the geological area (soil type) of this area is soil mixed with boulder stone and with shallow pipe cover depth. At this point/area, there is some movement due to low pipe cover to attach the laid pipe to the ground and this movement leads to friction between pipe and boulder stone which found in the base soil of the pipe due to the absence of proper pipe bidding and gradually form holes on a pipe like as shown on the figure below.



*Figure 4.5.3 uPVC pipe burst insufficient buried depth*

Since, there is no pipe bedding practiced in this area, total buried depth of pipe is the total depth of the trench excavation reduced by thickness of pipe bedding which is the sum of the covered pipe above pipe buried (above crown pipe) and the diameter of laid pipe. When compared pipe cover with standard pipe cover under different conditions (normal path and carriage path) of different points (at pipe burst points and at not pipe burst points) as shown on the figure 4.5.4 and figure 4.5.5.

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Table 4.5.1 Pipe cover, total buried depth at pipe burst points

Label	Type of pipe	Total buried depth(m)	Pipe Cover (m)	Normal pipe cover (m)	Maximum pipe cover (m)
B1	uPVC	0.68	0.4	0.6	1
B2	uPVC	1.33	1.06	0.6	1
B3	uPVC	1.18	0.85	0.6	1
B4	uPVC	1	0.8	0.6	1
B5	HDPE	0.65	0.5	0.6	1
B6	HDPE	0.52	0.42	0.6	1
B7	HDPE	0.4	0.3	0.6	1
B8	HDPE	0.7	0.62	0.6	1
B9	HDPE	0.72	0.65	0.6	1

Note B= burst

Source: Field measures

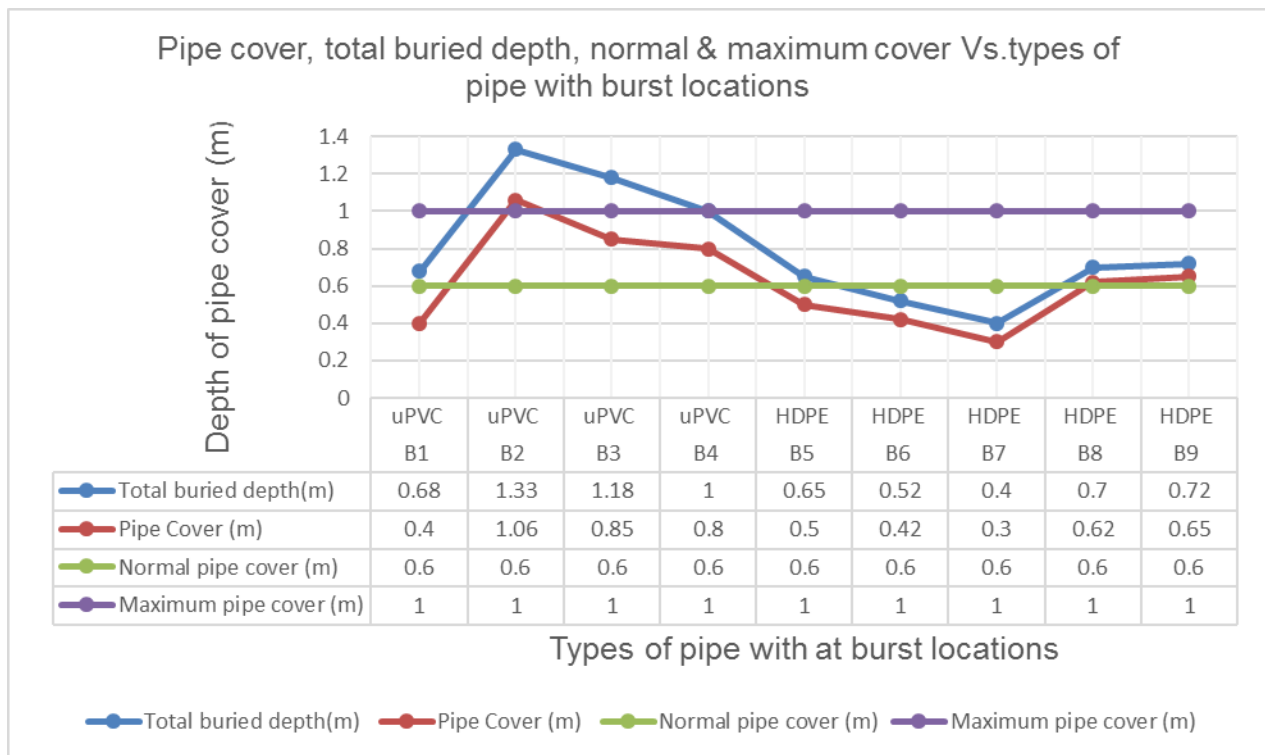


Figure 4.5.4 Pipe cover, total buried depth at pipe burst points

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At pipe burst points (B2, B3, B4, B8 and B9), greater than the normal pipe cover depth. So, the depth of pipe cover is satisfy the standard of the normal depth of pipe cover (under normal condition). But, pipe failure/burst appeared at these points. So, at these points other factors are the causes of pipe failure than the pipe cover depth. At pipe burst points (B1, B5, B6 and B7), below the normal pipe cover depth. So, the depth of pipe cover at these points are not satisfy under normal conditions and at these points pipe cover depth is the cause of pipe failure at these points.

*Table 4.5.2 Pipe cover, total buried depth at no pipe burst points*

Label	Type of pipe	Total buried depth(m)	Pipe Cover (m)	Normal pipe cover (m)	Maximum pipe cover (m)
J_3	DCI	1.08	0.8	0.6	1
J_10	uPVC	1.31	1.04	0.6	1
J_15	uPVC	1.2	0.87	0.6	1
J_86	uPVC	1.05	0.85	0.6	1
J_36	DCI	0.83	0.68	0.6	1
J_154	HDPE	0.81	0.71	0.6	1
J_160	HDPE	0.9	0.8	0.6	1
J_210	GI	0.65	0.6	0.6	1
J_221	GI	0.68	0.61	0.6	1

Note B= burst

Source: Field measures

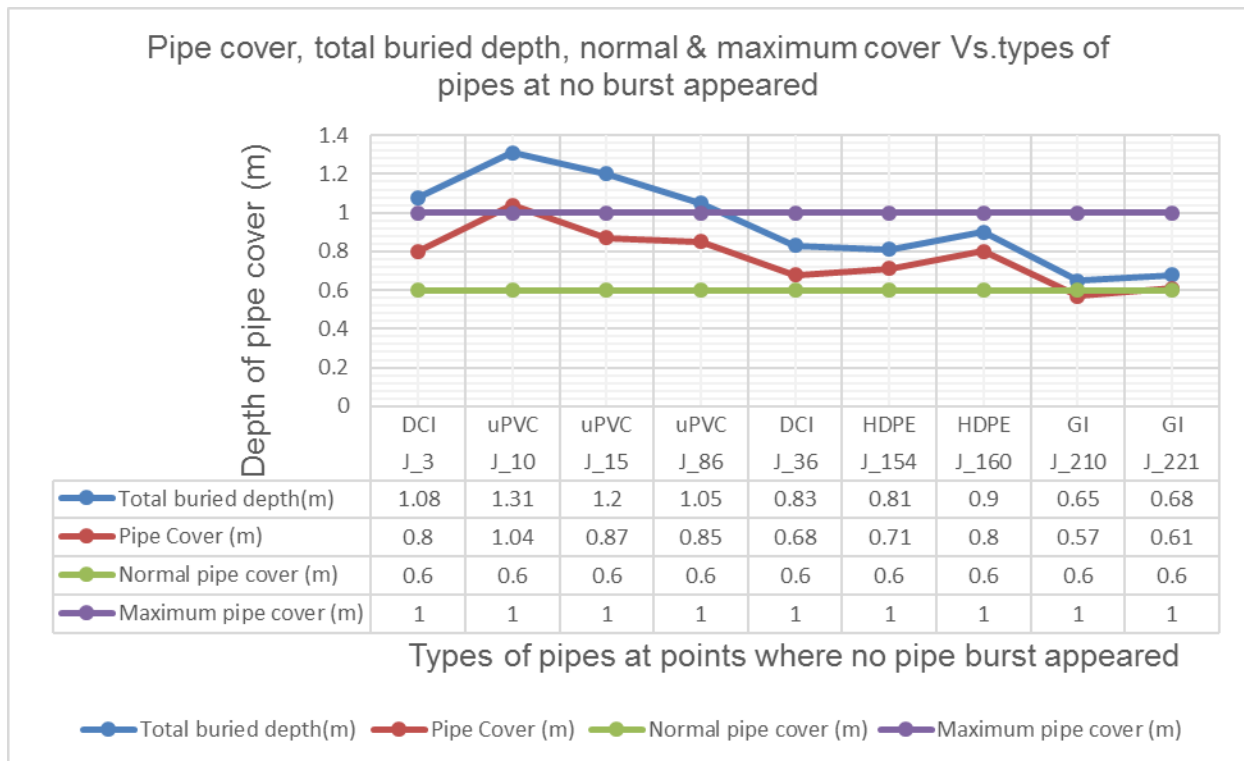


Figure 4.5.5 Pipe cover, total pipe buried depth at no pipe burst points

Almost at all points the pipe cover is satisfy the normal pipe cover depth (under normal conditions or path).

From investigations of the pipe failure/burst concerning installation conditions, pipe failure was occurred at both insufficient and sufficient pipe cover due to the poor installation practiced such as absence of pipe bedding and back fill with selected materials because of the pipe laid (especially transmission line and main distribution line) in the rocky area (soil mixed with stone). At these areas must properly installation of pipe is necessary for sustainability of the system due to the pipe laid in these area was plastic pipe. And also the probability of the pipe failure at low pipe cover is high especially at transmission line due to the pipe laid in the farmer land and farmer penetrated during ploughing their land by pick axe and lack of pipe bedding and back fill with selected materials example at burst (B1) and due to the lack of pipe bedding and back fill with selected materials example burst (B2, B3 and B4) with exerted internal water pressure. Even though, sufficient pipe buried depth with required pipe cover at where pipe burst appeared points, pipe burst due to poor installation practiced (pipe

bedding and backfill and low pipe cover). As a pipe cover decreases the probability of the pipe failure (of plastic pipe) is increase with the absence of pipe bedding and backfill due to the most pipe laid in the soil mixed with boulder stone and rocky area.

At where pipe failure wasn't appeared, almost at all points (selected points) the pipe cover is greater than the standard pipe cover depth, unfortunately soil found at these points are normal soil (soil which has no mixed stone or no rocky area) and also due to the material selections (pipes). So, pipe cover depth is one factor of the pipe burst with other factors such as poor installation of pipe (pipe bedding and types of soil which used for backfill) and due to pipe selection at these locations/areas and materials selection with its PN of the materials.

#### 4.4.3 Hydraulic conditions

##### 4.4.3.1 Internal water pressure

Internal water pressure is one of the factors that contributes the town pipe burst factor especially in plastic pipe segment throughout the system. According to the FDRE, MoWR, 2006, the normal operating internal water pressure head range was 60 to 70m and above 70m may lead to bursting of pipe. But, more pressure appeared in the system from simulated model or during the running of developed water distribution layout, 54.15% of total pressure in distribution system are greater than 70m. These pressure distribution in the system are shown in the table 4.5.3 below.

*Table 4.5.3 Distribution of the pressure in the system from simulated model*

Pressure Variation range (mH <sub>2</sub> O)	Percentage
≤0	1.75%
0-5	1.75%
5-10	2.62%
10-15	3.06%
15-20	3.49%

20-25	6.11%
25-30	3.49%
30-35	1.31%
35-40	3.93%
40-45	2.18%
45-50	3.06%
50-55	2.62%
55-60	3.06%
60-65	3.49%
65-70	3.93%
≥70	54.15%

#### 4.5.3.1.1 Comparison of simulated and measured pressures

Field measurement of pressures were occurred at different locations where the pipe burst were observed and where not appeared. These pressures are taken three times in a day for nine consecutive days as shown in **appendix A**. This situation used for comparisons of simulated pressure from developed distribution layout to the reality of the pressure in the system at selected points. The relationship of simulated pressures with measured pressures at where pipe burst was appeared and not pipe burst was appeared as shown on the figure 4.5.4.1 and figure 4.5.4.2 below.

*Table 4.5.4 Field measures and simulated pressure at frequently pipe burst was appeared*

Label	Types of pipe	Diameter (m)	PN(m)	Measured pressure(m)	Simulated pressure (mH <sub>2</sub> O)	Simulated velocity (m/s)
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B1	uPVC	0.250	100	63	69	2.26
B2	uPVC	0.250	100	27	9	2.26
B3	uPVC	0.300	100	81	90	6.16
B4	uPVC	0.150	100	74	66	0.41
B5	HDPE	0.100	160	103	101	0.66
B6	HDPE	0.100	160	42	40	0.33
B7	HDPE	0.100	160	35	49	1.39
B8	HDPE	0.080	160	115	122	1.29
B9	HDPE	0.050	160	159	169	0.78

Source: Field measures

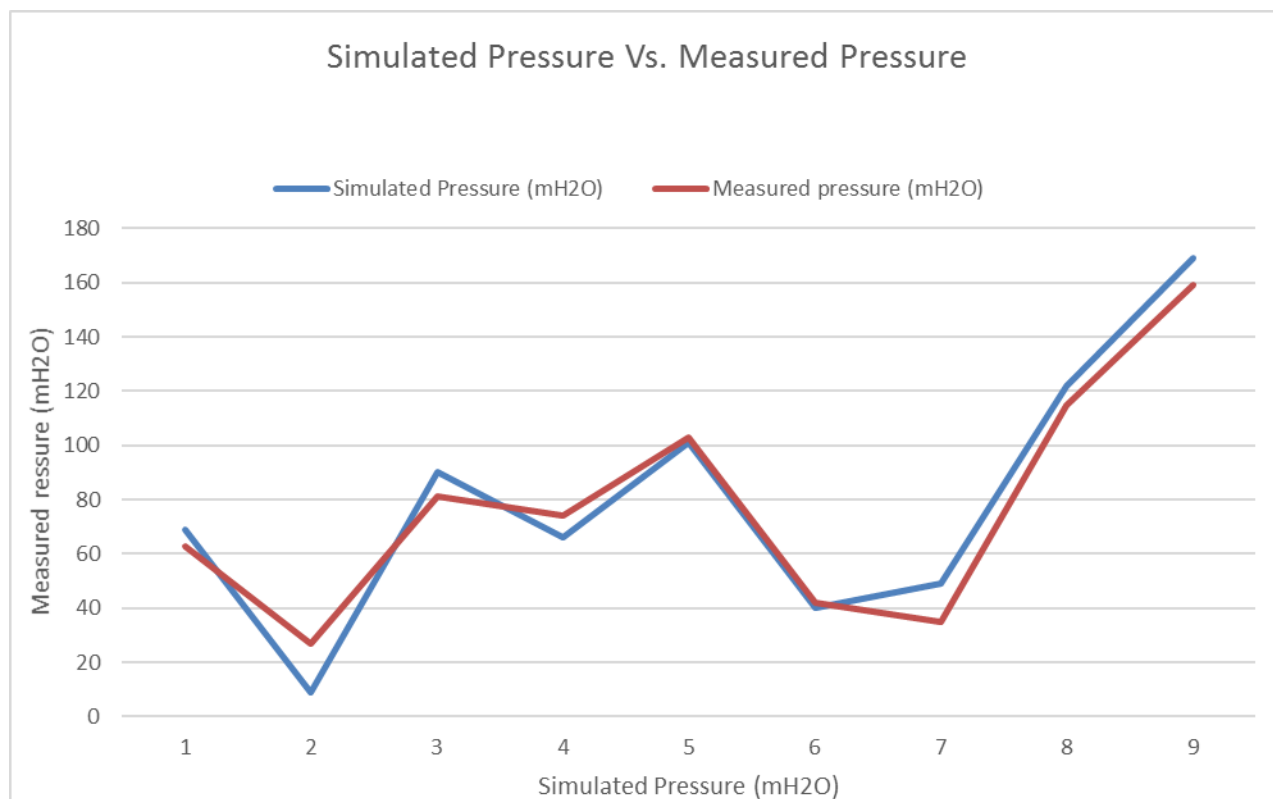


Figure 4.5.4.1 Relation between simulated pressure and measured pressure at where pipe failure was appeared

When compared the pressure appeared in the system (simulated and measured pressure) at these points where frequently pipe failure appeared to the allowable pressure, pressure appeared in these points are (B4, B5, B8 and B9) greater than allowable pressure (70m). So, at these points internal water pressure is one of the factor that contribute the pipe burst at these points. And points (B1, B2, B3, B6 and B7)

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are not exceed the allowable pressure (70m). So, at these points other factor is the cause of pipe failure than internal water pressure.

Table 4.5.5 Field measures and simulated pressure at pipe burst was not appeared

Label	Types of pipe	Diameter (m)	PN(m)	Measured pressure(m)	Simulated pressure (mH2O)	Simulated velocity (m/s)
J_3	DCI	0.200	160	88	93	2.26
J_10	uPVC	0.250	100	6	2	2.26
J_15	uPVC	0.300	160	100	103	6.18
J_86	uPVC	0.150	160	85	88	1.09
J_36	DCI	0.250	160	131	138	2.38
J_154	HDPE	0.100	160	102	88	1.13
J_160	HDPE	0.050	160	19	10	0.33
J_210	GI	0.050	160	85	82	0.56
J_221	GI	0.040	160	110	118	0.71

Source: Field measures

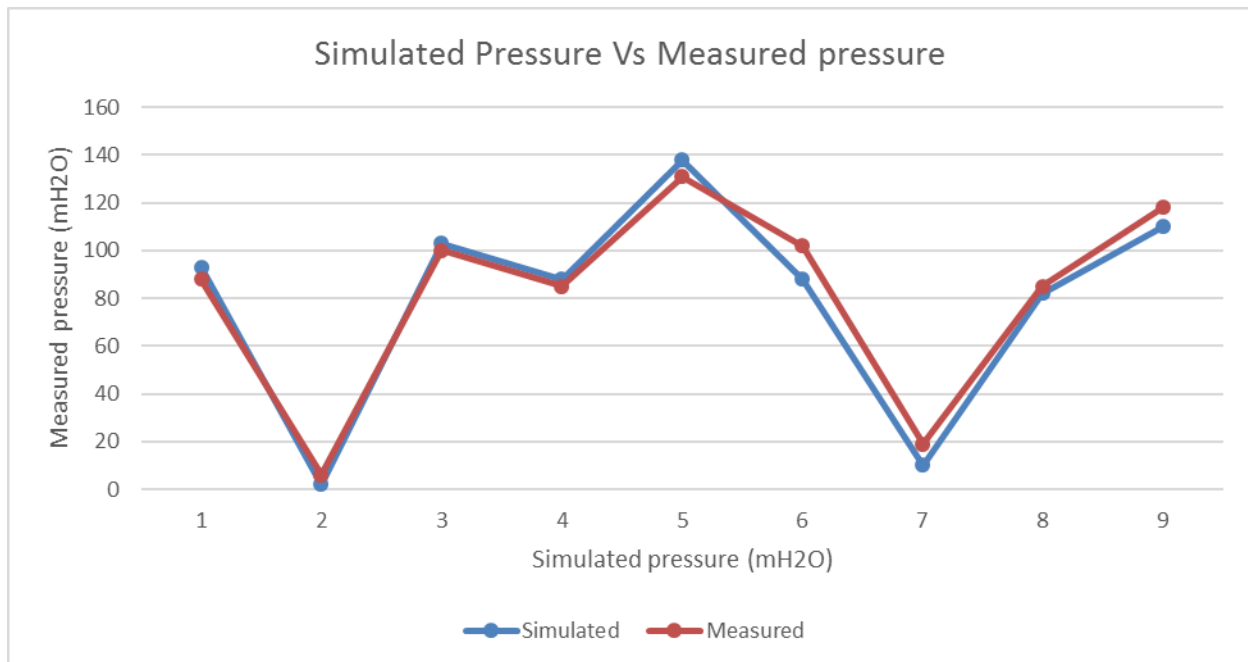


Figure 4.5.4.2 Relation between simulated pressure and measured pressure at where pipe was not burst appear

#### 4.5.3.1.2 Calibration and validation works

Calibration is an iterative process of comparing the simulated model to the observed/real system and making adjustments. So, in this research it is an iterative process of comparing the simulated pressure with observed pressure for selected points (junctions) at where pipe frequently burst was appeared throughout the network system and made adjustment. Even though the required data have been collected and entered into a hydraulic simulation software package, the system cannot assume that the analysis is an accurate mathematical representation of the system. So, adjusting the data is favorable until reasonably agrees with measured data and finally validate the model which means the overall process of comparing the model and its behavior to the observed pressure in the system which leads to burst pipe.

#### Calibration of works

At this thesis calibration can be done by using water GEMS software, having C-factors of pipes and considering different variables such as pipe diameter, pipe buried depth to detect the pipe failure/burst causes throughout the system.

*Table 4.5.6 Points where pipe failure/burst appear having C-factors*

Label	Types of pipe	Pipe diameter(m)	PN(m)	C-Factor	Measured pressure (mH2O)	Simulated Pressure (mH2O)
B1	uPVC	0.25	100	130	63	69
B2	uPVC	0.25	100	130	27	9
B3	uPVC	0.3	100	130	81	86
B4	uPVC	0.15	100	130	74	66
B5	HDPE	0.1	160	130	103	101
B6	HDPE	0.1	160	130	42	40
B7	HDPE	0.1	160	130	35	49
B8	HDPE	0.08	160	130	115	122
B9	HDPE	0.05	160	130	159	169

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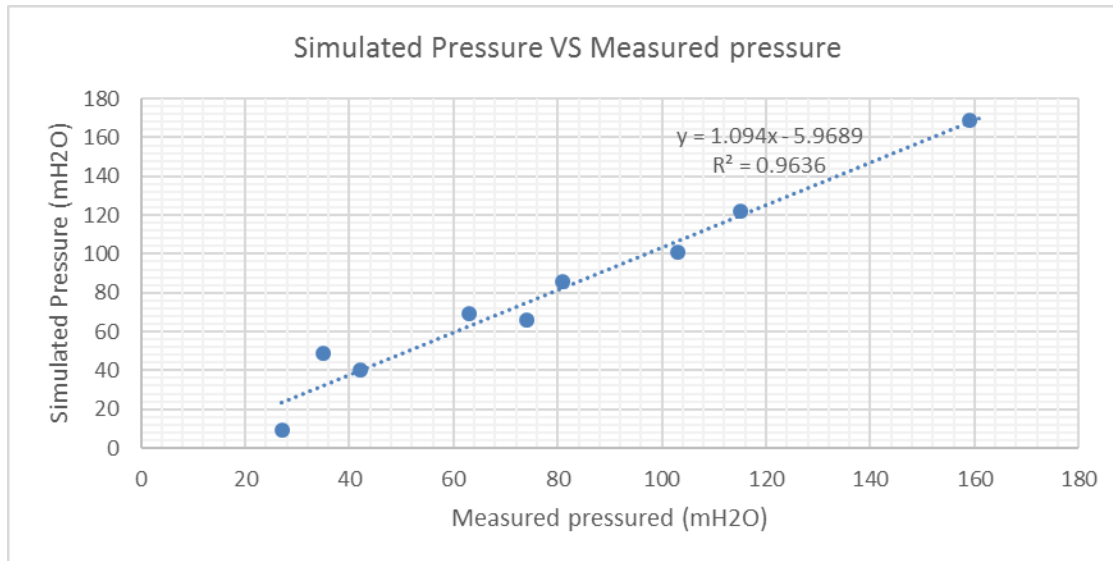


Figure 4.5.4.3 Correlation between observed and simulated water pressure at where pipe burst appeared

Label	Types of pipe	Pipe diameter(m)	PN(m)	C-Factor	Measured pressure (mH2O)	Simulated Pressure (mH2O)
B1	uPVC	0.25	100	120	63	75
B2	uPVC	0.25	100	120	27	9
B3	uPVC	0.3	100	120	81	91
B4	uPVC	0.15	100	120	74	66
B5	HDPE	0.1	160	120	103	101
B6	HDPE	0.1	160	120	42	40
B7	HDPE	0.1	160	120	35	49
B8	HDPE	0.08	160	120	115	120
B9	HDPE	0.05	160	120	159	168

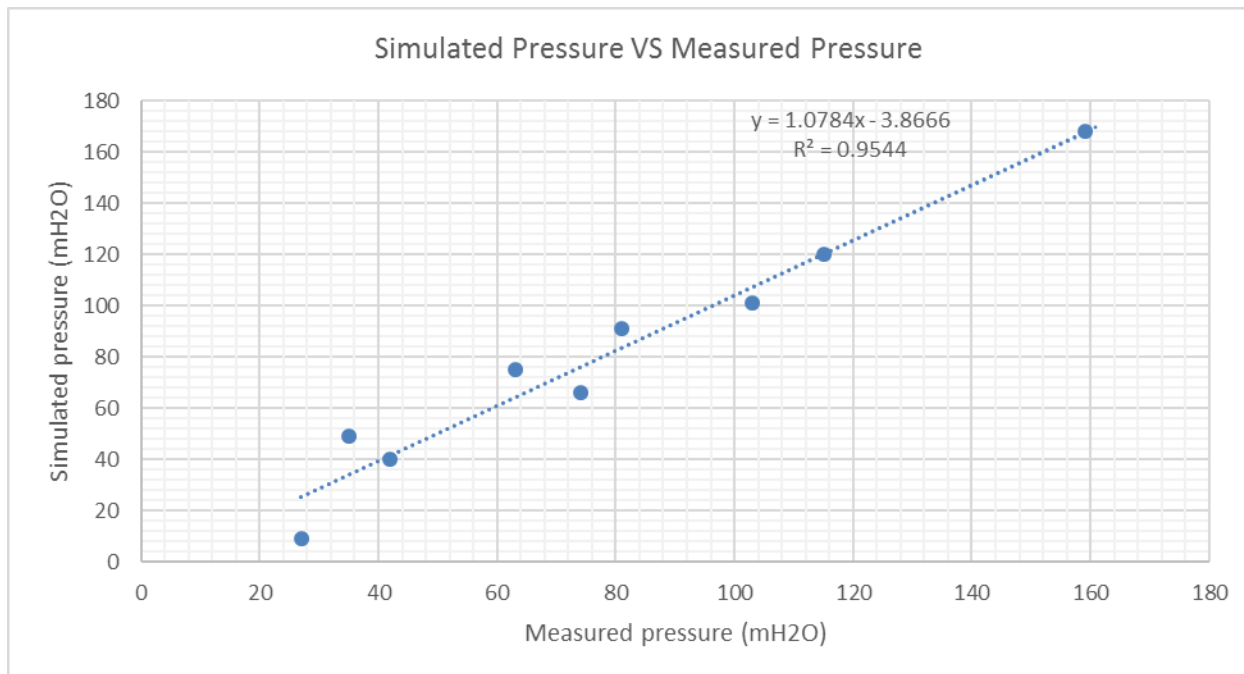


Figure 4.5.4.4 Correlation between observed and simulated water pressure at where pipe burst appeared

According to these iteration processes at where pipe burst were appeared at points (B1, B2 and B3) as a C- factors of a pipe decreases the pressure appeared in these points will increase and at point (B4) water pressure constant and also at points (B5,B6,B7,B8,B9) water pressure decreases when C-factors of a pipe decreases.

Table 4.5.7 Points where pipe failure/burst appear having variable pipe size (diameter)

Label	Types of pipe	Pipe diameter(m)	PN(m)	C- Factor	Measured pressure (mH2O)	Simulated Pressure (mH2O)
B1	uPVC	0.25	100	130	63	69
B2	uPVC	0.25	100	130	27	9
B3	uPVC	0.3	100	130	81	86
B4	uPVC	0.3	100	130	74	67
B5	HDPE	0.2	160	130	103	103
B6	HDPE	0.2	160	130	42	43
B7	HDPE	0.3	160	130	35	50
B8	HDPE	0.1	160	130	115	126
B9	HDPE	0.1	160	130	159	170

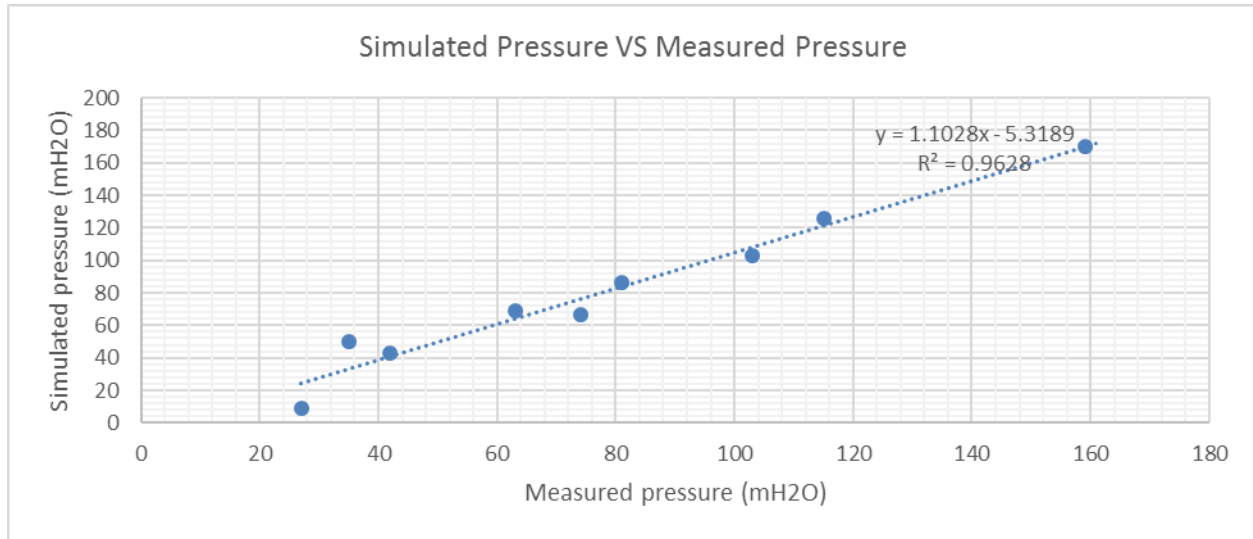


Figure 4.5.4.5 Correlation between observed and simulated water pressure at where pipe burst appeared

Label	Types of pipe	Pipe diameter(m)	PN(m)	C-Factor	Measured pressure (mH2O)	Simulated Pressure (mH2O)
B1	uPVC	0.2	100	130	63	124
B2	uPVC	0.2	100	130	27	11
B3	uPVC	0.25	100	130	81	91
B4	uPVC	0.25	100	130	74	67
B5	HDPE	0.15	160	130	103	102
B6	HDPE	0.15	160	130	42	42
B7	HDPE	0.25	160	130	35	49
B8	HDPE	0.08	160	130	115	122
B9	HDPE	0.08	160	130	159	169

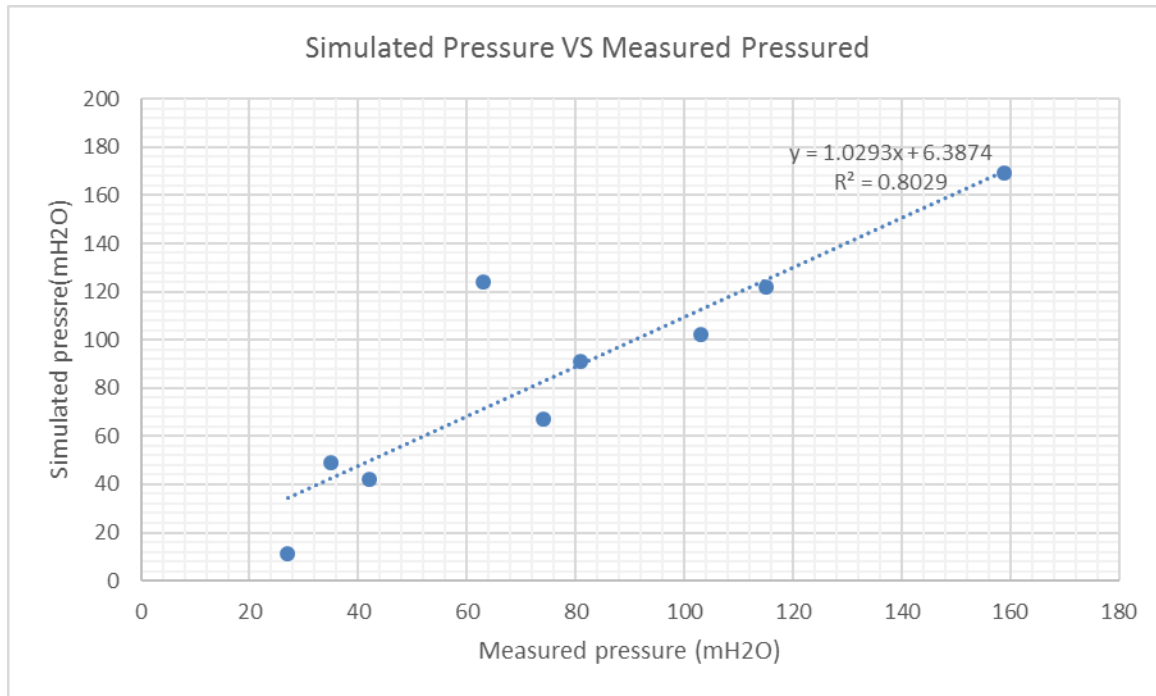


Figure 4.5.4.6 Correlation between observed and simulated water pressure at where pipe burst appeared

Table 4.5.8 Points where pipe doesn't failure/burst appear

Points	Diameter(m)	Simulated pressure (m)	Measured pressure(m)
J_3	0.3	93	88
J_10	0.3	1	6
J_15	0.3	98	100
J_86	0.2	91	85
J_36	0.3	143	131
J_154	0.15	89	102
J_160	0.1	10	19
J_210	0.1	88	85
J_221	0.1	120	118

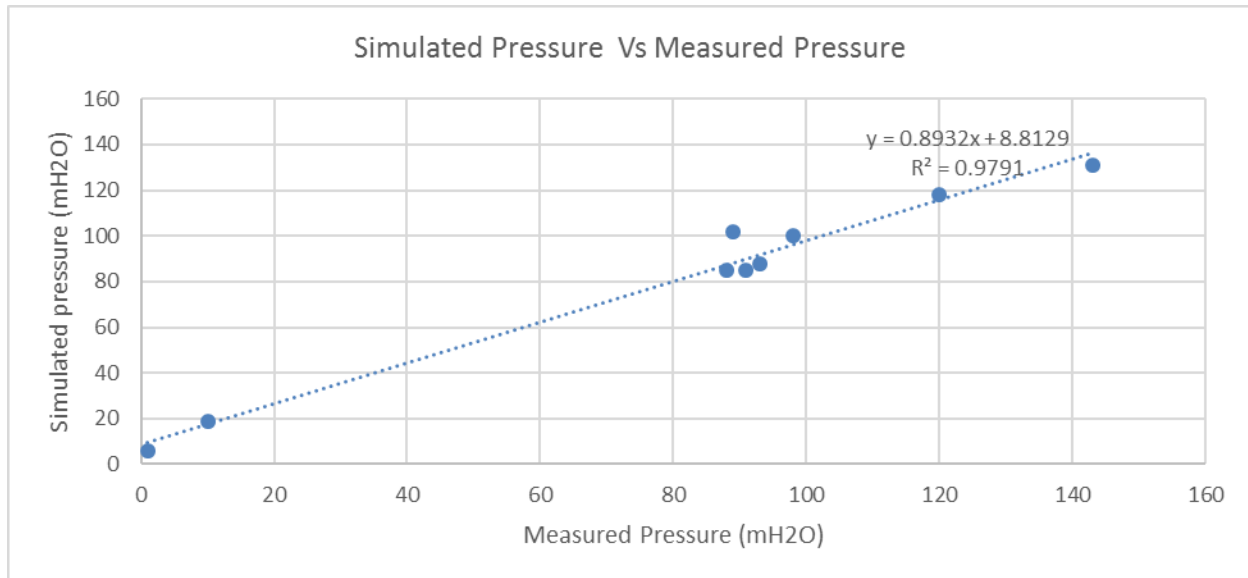


Figure 4.5.4.7 Correlation between observed and simulated water pressure at where pipe was not appeared

As diameter of a pipe decreases pressure increases and velocity increase at points (B1,B2) and as a diameter of a pipe decreases pressure also decreases and velocity increase at points(B4, B5, B6, B7, B8 and B9). Also iteration processes at where pipe burst was not appear as a diameter of a pipe decrease the pressure increase and flow velocity increase at point (J-10) and vice versa and also as a diameter of a pipe decreases pressure also decreases and flow velocity increases and vice versa at points (J-3, J-15, J-86, J-36, J-54, J-160, J-210 and J-221). As a pipe buried depth increases, some instant of pressure increases and velocity decreases but not greater variation at all selected points.

### Validation Works

The model validation work was taken manually using the correlation coefficient equation ( $R^2$ ) method. In this research model validation works were used both Pearson correlation coefficient equation ( $R^2$ ) and Simple linear regression. Because both used to investigate if two numerical variables are linearly related and both used to quantify the direction and strength of the linear relationship between two numerical variables. In Pearson correlation coefficient equation ( $R^2$ ) both variables (along X and Y axis) are assumed to be random variables or simply indicate the relation between two variables or best correlation between observed and simulated water pressure by using Water GEMS software. According to (Tomas, et al., 2003), the calibration process was

performed by adjusting sensitive parameters related with flow; like pipe roughness coefficient and water pressure until it was become within the acceptable limit of 85% of field test measurements (it should be within  $\pm 0.5$  m or  $\pm 5\%$  of the maximum head loss across the system, whichever is greater) and then finally it was validated manually using the correlation coefficient ( $R^2$ ) method using Microsoft Excel sheet. It explain the results of correlation value ( $R^2$ ) for peak pressure at selected junctions were represents as 96% and 97.9%. So, the calibrated pressure value was validated within the recommended standard or near to 1 or this indicates that more related of measured/observed pressure with simulated pressure at both where pipe failure/ burst points and where pipe doesn't burst appeared till this data was collected.

When compare the different points at where pipe burst were appeared and where not appear having different parameters which causes pipe failure or not. These points are related based on the location/ area which found in. Which means found in the same location/area/near to each other or under the same situations. Even though found at the same locations, found under different conditions such as at one point pipe failure appeared and at the other point doesn't appear due to different parameters as shown below:

**At point B1 and J\_3:** Different diameters which means the diameter at no pipe burst appear (J\_3) is less than the diameter at pipe burst appear (B1) (i.e 200mm and 250mm) respectively. In transmission line (pumping main line), consider the pipe failure due to the internal water pressure during the design work of the system. For plastic pipes (uPVC and HDPE pipes) in pumping main line, the total pressure variations from minimum to maximum should not exceed 50% of the nominal working pressure of the pipe (PN of the pipe) used at this location/area in order to prevent pipe from burst and also flow velocity found in the main line not exceed 0.8m/s and also for other types of pipes(DCI and GI) internal water pressure doesn't exceed the PN of the pipe (The Republic of Uganda Ministry of Water and Environment, Water supply design manual second edition, 2013).At these points there are different scenarios were appeared. Such as water pressure (at B1 and J\_3 both simulated/measured respectively 69/63mH<sub>2</sub>O and 93/88 mH<sub>2</sub>O), different pipe cover depth (i.e B1=0.4m, J\_3=0.8m) and different types of materials (i.e B1=uPVC, PN10 and J\_3= DCI, PN16). In this point the pressure

head (HGL) or the elevation difference between at pipe burst point and at elevation of pressure break is not greater than the PN of the pipe which found at this location which is 34m. But, pressure appeared at these points are greater than 50% of the PN of the pipe (69/63 >50% of PN10 and 93/88 < PN16). So, the causes of pipe failure at this point is due to the selections of pipe materials or used uPVC pipe at where pipe burst was appeared and DCI pipe at where pipe burst doesn't appear and poor pipe installation conditions (shallow pipe cover and absence of pipe bedding and backfill with selected materials) since the area is soil mixed with boulder stone and due to the internal water pressure also the low PN of the pipe.

**At point B2 and J\_10:** The same diameters, type of materials (250mm, uPVC pipe, PN10), almost the same pipe cover depth (i.e H=1.06m and 1.04m) respectively. Pressure occurred (at B2 and J\_10 both simulated/measured respectively 9/27mH<sub>2</sub>O and 2/6 mH<sub>2</sub>O) both pressures appeared at these locations are much less than 50% of the PN of pipe used in this points/area. Even though low pressure appeared, pipe failure occurred at point (B2) due to other factors such as poor pipe installation conditions and selection of materials in the rocky area (DCI pipe is selected than plastic (uPVC) pipe).

**At point B3 and J\_15:** The same diameters and types of materials (250mm, uPVC), different pressure (both simulated/measured pressure respectively 90/81mH<sub>2</sub>O and 103/100 mH<sub>2</sub>O) respectively and almost the same velocity ( $\approx 6.2$ m/s), the same pipe cover depth (H=0.85m and 0.87m) and different PN of the pipe (at B3=PN10 and J\_15=PN16). But, pressure appeared at these points and velocities are greater than allowable pressure (i.e 70m) and flow velocity (3m/s) in the water supply distribution system. At any point in the transmission line (gravity main line), the maximum HGL should not be over the allowable maximum pressure of the line (70 m head). To limit the maximum pressure, break pressure tanks or chambers could be installed along the main if hydraulic grade line (HGL) greater than 100m (World bank rural/urban water supply design manual Vol1, 2006). At these points, HGL between existing pressure break and at this pipe failure (B3) location is much greater than maximum allowable HGL (340.79m>100m) so, before this point needs other pressure break for reduction of pipe failure at this point. And pressure appeared at this area is greater than maximum allowable (90/81m and 103/100m>70m). And also flow velocity occurred at this points

are greater than maximum allowable flow velocity in water distribution system (6.16m/s and 6.18m/s >3m/s). This condition appeared due to the high elevation different at pressure break to this point/location which is 340.79m and the location area is undulation form or not uniform area. So, the causes of pipe failure at this point (B3) is a lack of material selection with appropriate PN, due to pressure appeared at this point and high flow velocity and also poor pipe installation conditions.

**At point B4 and J\_86:** The same pipe diameter and types of pipes and different PN (150mm, uPVC, PN10, PN16) respectively, almost the same pipe cover depth (H= 0.8m and 0.85m) and different pressures and velocity (i.e 66/74 mH<sub>2</sub>O, 88/85 mH<sub>2</sub>O, and 0.41m/s, 1.09m/s) respectively. Hydraulic grade line at this point (64m) from service reservoir #1 to the pipe burst point is less than the PN of the pipe used (64m < PN10 or 100m). Pressure appeared at these area were less than pipe nominal pressure (PN) and also less than allowable pressure at point where pipe burst was appeared (B4) and greater at where pipe doesn't burst appeared (J\_86). Even though greater pressure appeared at J\_86 pipe at this point/ area failure of pipe doesn't appeared and less pressure appeared at B4, failure of pipe appeared due to the different types of soil which laid pipe though (B4 laid in rock area with the absence of pipe bedding and back fill with selected materials and at J\_86 pipe laid in normal soil which has no rock or stone).

**At points B5, B6, B7 and J\_154:** The same types of materials, pipe diameters and also the same PN of the pipe (HDPE, 100mm, PN16). But, different pressures and velocities (at B5, P=101/103mH<sub>2</sub>O, 0.66m/s, and at J\_154, P= 88/102mH<sub>2</sub>O, 1.13m/s). HGL at this point (103m) from service reservoir #2 this is greater than allowable maximum HGL in the water distribution system (100m) but less than the PN of pipe used at this location. Also pressure appeared at this point (B5) greater than allowable pressure (101/103mH<sub>2</sub>O and 88/102mH<sub>2</sub>O > 70m). So, the causes of pipe failures in this point is due to the pressure (101/103mH<sub>2</sub>O and 88/102mH<sub>2</sub>O > 70m) and poor pipe installation conditions (absence of backfill with selected materials). At B6, B7 and J\_154: the same types of materials, pipe diameters and also the same PN of the Pipe (HDPE, 100mm, PN16). But, different pressures, total pipe buried depth and velocities (at B6, P=40/42 mH<sub>2</sub>O, H= 0.52m, V= 0.33m/s, at B7, P= 49/35mH<sub>2</sub>O, H = 0.4m, V=

1.39m/s and at J\_154,  $P=88/102\text{mH}_2\text{O}$ ,  $H= 0.81\text{m}$ ,  $V= 1.13\text{m/s}$ ). So, the causes of pipe burst at this points are due to poor pipe installation conditions (absence of backfill with selected materials).

**At points B8, B9 and J\_160:** The same types of pipe materials (HDPE, PN16) but different pressures were appeared (simulated and measured pressure 122/115, 169/159 and 10/19 respectively), and also different diameters of pipe, pipe cover depth of pipe buried and velocities. Hydraulic grade line (pressure head) is less than the PN of the pipe used ( $43 < 160\text{m}$ ) and pressure appeared in this area is greater than allowable pressure ( $122/115, 169/159 > 70\text{m}$ ) where pipe burst was appeared and less than allowable pressure at where pipe doesn't burst. When compared velocities to the allowable velocity ( $1.29\text{m/s}, 0.78\text{m/s}, 0.33\text{m/s} < 3\text{m/s}$ ) and also pipe cover is greater than normal depth ( $0.62, 0.65, 0.8\text{m} \geq 0.6\text{m}$ ). So, the causes of the pipe failure at these points are the water pressures with poor pipe installation conditions.

From calibration and validation of developed equation, the probability of pipe burst appeared at points (B1, B2, B4, B6, B7) due to the poor installation practiced rather than hydraulic factor due to pressure appeared at these points are less than the allowable pressure (70m) and less than nominal pipe (PN). But, when applied the rule of pressure in transmission line (for plastic pipe) at pumping main or side, pressure appeared in the pipe not greater than 50% of the nominal pipe (PN) which laid in the point/location. But, at B1 ( $69\text{m} > 50\%$  of PN10) and so pipe burst at this point is due to the poor installation practiced with the low PN of the pipe. And the probability of pipe burst appeared at points (B3, B5, B8, and B9) due to internal water pressure with poor installation practiced because of the pressure appeared at these points are greater than the allowable pressure

## CHAPTER FIVE

### 5. Conclusions and Recommendations

#### 5.1 Conclusions

Chiro town water supply distribution system was constructed from four types of pipes such as DCI (300mm, 250mm and 200mm), uPVC (300mm, 250mm, 200mm, 150mm), HDPE (100mm, 80mm, 50mm) and GI (50mm, 40mm). The proportion of pipe in the system is DCI (6.33%), uPVC (36.67%) HDPE (52.5%) and GI (4.5%) pipe with a total length of 54753m. From different investigations on the causes of pipe failure/burst appeared in the system, frequently pipe failure appeared in water distribution networks on plastic pipe (uPVC and HDPE) than the other pipes due to the different factors, such as poor pipe installation conditions (absence of pipe bedding and backfill with selected materials at rocky area), high pressure above allowable pressure (70m), types of material selections and absence of material selections with appropriate locations/ in geological formations (soil types such as normal soil or rock) of the area which pipe laid through. Area where pipe failure frequently failures/bursts were appeared in transmission lines and distribution lines. According to Chiro town water supply distribution system, pipe installation age was not the causes of the pipe failure in the system.

Chiro town water distribution system doesn't provide adequate supply water to the town, due to repetitive pipe burst and significant water loss. So, due to this problems, an interruption of water supply and shortage of water supply appeared in the town.

In general, the main causes of the pipe failure (burst) in Chiro town water supply distribution system is due to the types of pipe selection with its PN, water pressure, poor pipe installation practiced during construction.

## 5.2 Recommendations

Based on the findings of this research the following recommendations are given to improve the performance of Chiro town water supply system.

- Proper recording of pipe burst history which have the location, date, type and installation date of pipe, pipe installation details such as pipe bedding, cover, depth and also causes of pipe burst should be documented consistently. To decrease pipe bursting there should be proper selection of pipe type with appropriate its PN considering the sub-surface conditions of pipe laying route. It is better to use DCI and GI pipe in rocky areas and plastic pipes where there is no rock.
- For transmission lines DCI pipes with PN ( $\geq 16$ ) should be used instead of plastic pipes. In distribution pipe increase pipe nominal pressure of PN 16 or above for uPVC pipe instead of PN10 and practice good installation condition (appropriate pipe bedding, pipe cover and pipe backfill with selected materials).
- It is good if use GI pipe for distribution line unless use plastic pipes in distribution lines
- Two air release valves were appeared at the downstream of pressure break (between pressure break and distribution reservoir) to reduce pressure appeared in the pipe due to pressure head. In order to reduce/minimize pressure which leads to pipe burst due to high pressure head (the different between existing pressure break and pipe burst point (B3)) which is greater than the nominal pressure (PN10 and PN16), use additional pressure break instead of air release valves which found between existing pressure break and distribution reservoir.
- In order to minimize the risks of pipe at point (B1), good if running time of the two pumps are not use as the same time or operate in different time to the reduce the flow disturbance at the points.

- To minimize risks of pipe failures due to physical factors and poor installation of the pipe provision of sufficient depth of trench, proper bedding and cover material with appropriate thickness is recommended.

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## APPENDIXS

### Appendix A

Observed pressure at frequently pipe burst was appeared

Time (hr)	Pressure junctions	Observed pressure (m H2O)
7:00AM	B1 (J_4)	63
	B2 (J_B2)	27
	B3 (J_20)	81
	B4 (J_B4)	74
	B5(J_169)	103
	B6(J_172)	42
	B7 (J_125)	35
	B8 (J_186)	115
	B9 (J_177)	159
2:00PM	B1 (J_4)	63
	B2 (J_B2)	27
	B3 (J_20)	80
	B4 (J_B4)	30
	B5(J_169)	55
	B6(J_172)	28
	B7 (J_125)	21
	B8 (J_186)	67
	B9 (J_177)	79
6:00PM	B1 (J_4)	63
	B2 (J_B2)	27
	B3 (J_20)	78
	B4 (J_B4)	36
	B5(J_169)	61
	B6(J_172)	24
	B7 (J_125)	29
	B8 (J_186)	76
	B9 (J_177)	88

Observed pressure at pipe burst wasn't appeared

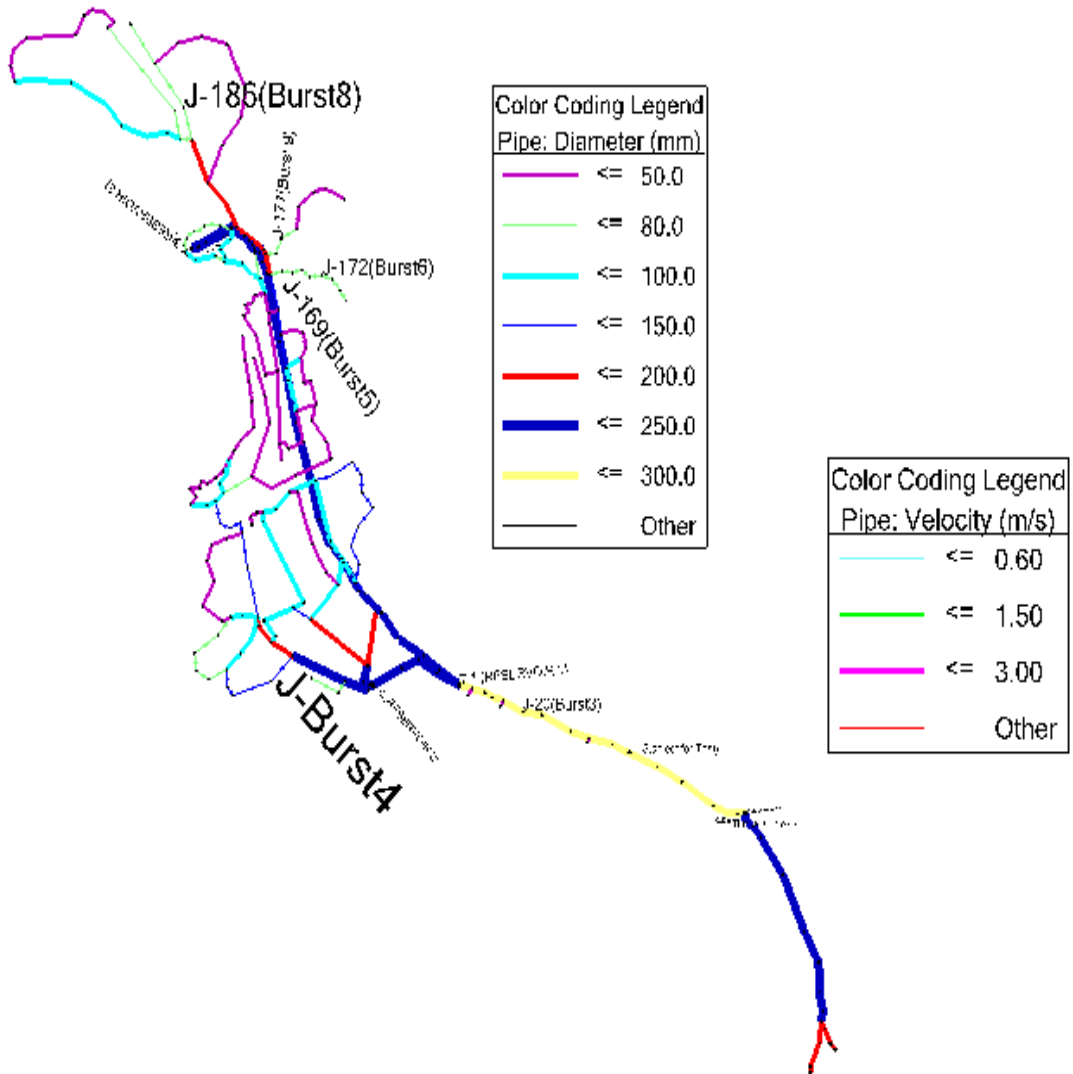
Time (hr)	Pressure junctions	Observed pressure (m H2O)
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7:00AM	J_3	88
	J_10	6
	J_15	100
	J_86	85
	J_36	131
	J_154	102
	J_160	19
	J_210	85
	J_221	110
2:00PM	J_3	88
	J_10	6
	J_15	98
	J_86	28
	J_36	63
	J_154	56
	J_160	4
	J_210	32
	J_221	49
6:00PM	J_3	88
	J_10	6
	J_15	95
	J_86	25
	J_36	57
	J_154	44
	J_160	2
	J_210	30
	J_221	41

Appendix B: Chiro Town water distribution system



Appendix C: Water GEMS reports

Pipe Report

Label	Length (Scaled) (m)	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/m)
P-3	75	200	Ductile Iron	120	88.391	2.81	0.043
P-6	191	200	Ductile Iron	120	22.606	0.72	0.003
P-7	91	250	PVC	130	110.996	2.26	0.019
P-8	169	250	PVC	130	110.996	2.26	0.019
P-9	262	250	PVC	130	110.996	2.26	0.019
P-10	305	250	PVC	130	110.996	2.26	0.019
P-11	546	250	PVC	130	110.996	2.26	0.019
P-12	399	250	PVC	130	110.996	2.26	0.019
P-13	127	250	PVC	130	110.996	2.26	0.019
P-15	77	300	PVC	130	436.874	6.18	0.099
P-16	264	300	PVC	120	436.874	6.18	0.114
P-17	387	300	PVC	130	436.874	6.18	0.099
P-18	354	300	PVC	130	436.874	6.18	0.099
P-19	260	300	PVC	130	436.874	6.18	0.099
P-20	186	300	PVC	130	436.874	6.18	0.099
P-21	242	300	PVC	130	436.874	6.18	0.099
P-55	49	40	Galvanized iron	120	1.1	0.88	0.032
P-22	199	300	PVC	130	435.774	6.16	0.098
P-23	331	300	PVC	130	435.774	6.16	0.098
P-24	200	300	PVC	130	435.774	6.16	0.098
P-25	226	300	PVC	130	435.774	6.16	0.098
P-56	59	40	Galvanized iron	120	1.1	0.88	0.032
P-26	117	300	PVC	130	434.674	6.15	0.098
P-27	86	300	Ductile Iron	130	434.674	6.15	0.098
P-28	137	300	PVC	130	434.674	6.15	0.098
P-29	135	300	PVC	130	433.574	6.13	0.097

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P-30	256	250	PVC	130	214.57	4.37	0.064
P-31	224	250	PVC	130	214.57	4.37	0.064
P-32	185	250	PVC	130	214.57	4.37	0.064
P-33	330	250	PVC	130	214.57	4.37	0.064
P-34	246	250	PVC	130	116.951	2.38	0.021
P-35	205	250	PVC	130	116.951	2.38	0.021
P-58	38	250	PVC	130	59.4	1.21	0.006
P-59	54	250	PVC	130	34.197	0.7	0.002
P-94	258	250	PVC	130	33.097	0.67	0.002
P-95	583	250	PVC	130	29.797	0.61	0.002
P-62	480	200	PVC	130	10.862	0.35	0.001
P-63	196	150	PVC	130	9.762	0.55	0.003
P-36	307	250	PVC	130	116.951	2.38	0.021
P-37	282	250	PVC	130	116.951	2.38	0.021
P-38	297	250	PVC	130	116.951	2.38	0.021
P-39	300	250	PVC	130	116.951	2.38	0.021
P-40	184	250	PVC	130	116.951	2.38	0.021
P-41	279	250	PVC	130	116.951	2.38	0.021
P-42	306	250	PVC	130	116.951	2.38	0.021
P-43	570	250	Ductile Iron	120	116.951	2.38	0.024
P-44	379	250	Ductile Iron	120	116.951	2.38	0.024
P-45	353	250	Ductile Iron	120	116.951	2.38	0.024
P-46	611	250	Ductile Iron	120	116.951	2.38	0.024
P-47	106	250	Ductile Iron	120	116.951	2.38	0.024
P-48	91	250	Ductile Iron	120	116.951	2.38	0.024
P-49	61	250	Ductile Iron	120	116.951	2.38	0.024
P-50	44	250	Ductile Iron	120	116.951	2.38	0.024
P-51	54	250	Ductile Iron	120	116.951	2.38	0.024
P-52	64	250	Ductile Iron	120	116.951	2.38	0.024
P-53	159	250	Ductile Iron	120	116.951	2.38	0.024
P-54	450	250	PVC	130	116.951	2.38	0.021
P-103	94	150	PVC	130	5.08	0.29	0.001

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P-104	156	150	PVC	130	5.08	0.29	0.001
P-120	204	80	HDPE	130	1.783	0.35	0.002
P-121	148	80	HDPE	130	1.783	0.35	0.002
P-105	210	100	HDPE	130	2.198	0.28	0.001
P-122	155	80	HDPE	130	0.683	0.14	0
P-123	288	80	HDPE	130	0.683	0.14	0
P-67	178	150	PVC	130	4.869	0.28	0.001
P-68	185	150	HDPE	130	4.869	0.28	0.001
P-69	225	150	HDPE	130	4.869	0.28	0.001
P-70	173	150	PVC	130	3.769	0.21	0
P-71	152	150	PVC	130	3.769	0.21	0
P-72	142	150	PVC	130	3.769	0.21	0
P-73	219	150	PVC	130	2.669	0.15	0
P-89	209	100	HDPE	130	0.77	0.1	0
P-88	134	100	HDPE	130	0.77	0.1	0
P-79	421	100	HDPE	130	3.108	0.4	0.002
P-74	199	150	PVC	130	2.669	0.15	0
P-90	286	100	HDPE	130	2.764	0.35	0.002
P-78	232	100	HDPE	130	0.702	0.09	0
P-76	198	100	HDPE	130	2.294	0.29	0.001
P-75	549	100	HDPE	130	1.194	0.15	0
P-82	119	100	HDPE	130	3.63	0.46	0.003
P-101	101	150	PVC	130	16.5	0.93	0.007
P-100	311	150	PVC	130	18.247	1.03	0.008
P-239	346	50	Galvanized iron	120	-1.1	0.56	0.011
P-238	239	50	Galvanized iron	120	-1.1	0.56	0.011
P-237	510	50	Galvanized iron	120	-1.1	0.56	0.011
P-240	500	50	Galvanized iron	120	2.2	1.12	0.039
P-241	395	50	Galvanized iron	120	1.1	0.56	0.011
P-140	76	250	PVC	130	68.2	1.39	0.008
P-141	84	250	PVC	130	68.2	1.39	0.008
P-142	290	250	PVC	130	68.2	1.39	0.008
P-159	150	250	PVC	130	59.505	1.21	0.006
P-158	172	250	PVC	130	59.505	1.21	0.006
P-175	142	100	HDPE	130	-6.227	0.79	0.008
P-156	235	100	HDPE	130	-3.495	0.44	0.003
P-195	104	100	HDPE	130	5.2	0.66	0.006

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P-196	100	100	HDPE	130	3.9	0.5	0.003
P-197	102	100	HDPE	130	3.9	0.5	0.003
P-198	125	100	HDPE	130	2.6	0.33	0.002
P-199	117	100	HDPE	130	1.3	0.17	0
P-208	217	50	HDPE	130	1.3	0.66	0.013
P-209	339	200	PVC	130	24	0.76	0.003
P-210	495	200	PVC	130	22.8	0.73	0.003
P-211	413	200	PVC	130	18.492	0.59	0.002
P-212	296	80	HDPE	130	6.492	1.29	0.025
P-213	487	80	HDPE	130	5.292	1.05	0.017
P-214	429	80	HDPE	130	1.2	0.24	0.001
P-219	83	50	HDPE	130	1.852	0.94	0.025
P-226	586	100	HDPE	130	-2.948	0.38	0.002
P-227	653	100	HDPE	130	-4.148	0.53	0.004
P-228	494	100	HDPE	130	-5.348	0.68	0.006
P-229	146	100	HDPE	130	-5.348	0.68	0.006
P-216	252	80	HDPE	130	4.252	0.85	0.012
P-215	120	80	HDPE	130	10.8	2.15	0.065
P-230	363	50	HDPE	130	3.108	1.58	0.064
P-231	312	50	HDPE	130	1.908	0.97	0.026
P-232	242	50	HDPE	130	1.908	0.97	0.026
P-233	445	50	HDPE	130	0.708	0.36	0.004
P-234	273	50	HDPE	130	-0.492	0.25	0.002
P-235	255	50	HDPE	130	-1.692	0.86	0.021
P-236	300	50	HDPE	130	-2.892	1.47	0.056
P-203	145	80	HDPE	130	3.9	0.78	0.01
P-204	183	80	HDPE	130	3.9	0.78	0.01
P-205	199	50	HDPE	130	2.6	1.32	0.046
P-206	199	50	HDPE	130	2.6	1.32	0.046
P-207	128	50	HDPE	130	1.3	0.66	0.013
P-66	165	150	PVC	130	-5.969	0.34	0.001
P-160	94	250	PVC	130	54.173	1.1	0.005
P-1	70	200	Ductile Iron	120	88.391	2.81	0.043
P-2	146	200	Ductile Iron	120	88.391	2.81	0.043
P-4	55	200	Ductile Iron	120	22.606	0.72	0.003
P-5	222	200	Ductile Iron	120	22.606	0.72	0.003
P-57	75	40	Galvanized iron	120	1.1	0.88	0.032

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P-60	69	250	PVC	130	25.203	0.51	0.001
P-61	149	250	PVC	130	24.103	0.49	0.001
P-80	720	200	PVC	130	12.141	0.39	0.001
P-81	201	150	PVC	130	7.933	0.45	0.002
P-64	134	150	PVC	130	9.762	0.55	0.003
P-77	253	100	HDPE	130	2.693	0.34	0.002
P-83	822	100	HDPE	130	2.53	0.32	0.001
P-96	259	200	PVC	130	21.416	0.68	0.003
P-93	72	100	HDPE	130	-2.103	0.27	0.001
P-92	183	100	HDPE	130	-2.103	0.27	0.001
P-91	325	100	HDPE	130	-3.203	0.41	0.002
P-97	190	200	PVC	130	22.42	0.71	0.003
P-98	74	200	PVC	130	22.42	0.71	0.003
P-106	366	100	HDPE	130	1.098	0.14	0
P-99	441	150	PVC	130	19.347	1.09	0.009
P-107	162	100	HDPE	130	3.071	0.39	0.002
P-108	118	100	HDPE	130	3.071	0.39	0.002
P-109	95	50	HDPE	130	1.553	0.79	0.018
P-139	209	80	HDPE	130	-0.417	0.08	0
P-110	242	50	HDPE	130	1.553	0.79	0.018
P-111	252	50	HDPE	130	0.453	0.23	0.002
P-112	188	50	HDPE	130	0.453	0.23	0.002
P-113	147	50	HDPE	130	0.453	0.23	0.002
P-114	161	50	HDPE	130	-0.647	0.33	0.003
P-115	171	50	HDPE	130	-0.647	0.33	0.003
P-116	122	150	PVC	130	15.4	0.87	0.006
P-117	113	150	PVC	130	15.4	0.87	0.006
P-118	205	150	PVC	130	15.4	0.87	0.006
P-122	102	100	HDPE	130	2.564	0.33	0.002
P-123	170	100	HDPE	130	2.564	0.33	0.002
P-124	93	50	HDPE	130	1.464	0.75	0.016
P-125	92	50	HDPE	130	1.464	0.75	0.016
P-126	101	50	HDPE	130	1.464	0.75	0.016
P-119	102	100	HDPE	130	11.736	1.49	0.026
P-120	96	100	HDPE	130	6.236	0.79	0.008
P-127	60	50	HDPE	130	1.464	0.75	0.016
P-128	70	50	HDPE	130	0.364	0.19	0.001
P-129	95	50	HDPE	130	0.364	0.19	0.001
P-130	97	50	HDPE	130	-0.736	0.37	0.004
P-131	110	50	HDPE	130	-0.736	0.37	0.004
P-121	230	100	HDPE	130	6.236	0.79	0.008

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P-132	102	50	HDPE	130	4.4	2.24	0.122
P-133	118	50	HDPE	130	3.3	1.68	0.072
P-134	167	50	HDPE	130	3.3	1.68	0.072
P-135	228	50	HDPE	130	2.2	1.12	0.034
P-136	183	50	HDPE	130	1.1	0.56	0.009
P-137	190	50	HDPE	130	1.1	0.56	0.009
P-138	214	50	HDPE	130	1.1	0.56	0.009
P-85	63	50	HDPE	130	1.1	0.56	0.009
P-86	77	50	HDPE	130	1.1	0.56	0.009
P-87	69	50	HDPE	130	1.1	0.56	0.009
P-84	84	100	HDPE	130	1.43	0.18	0.001
P-145	123	80	HDPE	130	2.504	0.5	0.004
P-146	94	80	HDPE	130	2.504	0.5	0.004
P-147	125	80	HDPE	130	2.504	0.5	0.004
P-148	142	100	HDPE	130	1.204	0.15	0
P-149	208	100	HDPE	130	1.204	0.15	0
P-155	192	100	HDPE	130	4.795	0.61	0.005
P-144	165	80	HDPE	130	2.504	0.5	0.004
P-152	81	100	HDPE	130	-6.191	0.79	0.008
P-153	140	100	HDPE	130	-6.191	0.79	0.008
P-154	96	100	HDPE	130	-6.191	0.79	0.008
P-143	121	80	HDPE	130	2.504	0.5	0.004
P-150	103	80	HDPE	130	-0.096	0.02	0
P-151	49	100	HDPE	130	6.191	0.79	0.008
P-174	175	50	HDPE	130	1.67	0.85	0.02
P-170	638	50	HDPE	130	0.727	0.37	0.004
P-169	147	50	HDPE	130	1.3	0.66	0.013
P-168	122	50	HDPE	130	-1.872	0.95	0.025
P-167	165	50	HDPE	130	-1.872	0.95	0.025
P-166	279	50	HDPE	130	-3.172	1.62	0.067
P-165	394	80	HDPE	130	-5.492	0.86	0.01
P-185	213	50	HDPE	130	1.02	0.52	0.008
P-161	47	200	PVC	130	-28.873	0.92	0.005
P-202	105	80	HDPE	130	3.9	0.78	0.01
P-191	141	50	HDPE	130	0.387	0.2	0.001
P-173	107	50	HDPE	130	-2.301	1.17	0.037
P-164	295	150	PVC	130	-10.059	0.57	0.003
P-163	217	150	PVC	130	-12.272	0.69	0.004
P-192	233	50	HDPE	130	-0.913	0.47	0.007
P-184	129	50	HDPE	130	0.643	0.33	0.003
P-183	359	50	HDPE	130	-0.657	0.33	0.004

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P-182	219	50	HDPE	130	-1.957	1	0.027
P-181	133	50	HDPE	130	-1.957	1	0.027
P-172	87	50	HDPE	130	2.671	1.36	0.048
P-171	427	50	HDPE	130	2.671	1.36	0.048
P-157	239	80	HDPE	130	4.032	0.8	0.011
P-180	84	50	HDPE	130	-3.257	1.66	0.07
P-179	75	50	HDPE	130	-3.257	1.66	0.07
P-178	99	50	HDPE	130	-3.257	1.66	0.07
P-189	174	100	HDPE	130	3.267	0.42	0.002
P-200	127	100	HDPE	130	1.3	0.17	0
P-201	107	100	HDPE	130	1.3	0.17	0
P-186	213	50	HDPE	130	-0.28	0.14	0.001
P-187	68	50	HDPE	130	-1.58	0.8	0.018
P-190	107	50	HDPE	130	0.387	0.2	0.001
P-188	221	50	HDPE	130	-1.58	0.8	0.018
P-218	1005	80	HDPE	130	3.052	0.61	0.006
P-220	267	50	HDPE	130	1.852	0.94	0.025
P-221	96	50	HDPE	130	0.652	0.33	0.004
P-222	192	50	HDPE	130	0.652	0.33	0.004
P-223	509	50	HDPE	130	-0.548	0.28	0.003
P-224	322	50	HDPE	130	-1.748	0.89	0.022
P-225	137	50	HDPE	130	-1.748	0.89	0.022
P-162	194	200	PVC	130	23.673	0.75	0.003
P-193	316	150	PVC	130	15.873	0.9	0.006
P-194	135	100	HDPE	130	6.5	0.83	0.009
P-217	327	80	HDPE	130	4.4	0.88	0.012
P-242	158	50	Galvanized iron	120	1.1	0.56	0.011
P-243	239	50	Galvanized iron	120	1.1	0.56	0.011
P-244	116	50	Galvanized iron	120	1.1	0.56	0.011
P-245	157	50	Galvanized iron	120	1.307	0.67	0.015
P-246	294	50	Galvanized iron	120	1.307	0.67	0.015
P-247	281	40	Galvanized iron	120	0.207	0.16	0.001
P-248	194	40	Galvanized iron	120	-0.893	0.71	0.022
P-249	119	80	HDPE	150	2.2	0.44	0.003
P-250	303	80	Galvanized iron	120	1.1	0.22	0.001

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P-102	320	150	PVC	130	7.28	0.41	0.001
P-B4	406	150	PVC	130	6.18	0.35	0.001
P-14	71	250	PVC	130	110.996	2.26	0.019
P-B2	84	250	PVC	130	110.996	2.26	0.019
P-p	88	40	Galvanized iron	120	-0.893	0.71	0.022

Junction Report

ID	Label	Elevation (m)	Zone	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H <sub>2</sub> O)
30	J-1	2211.46	<None>	0	2304.5	93
127	J-2	2212.16	<None>	0	2301.95	90
41	J-3	2208.57	<None>	0	2301.29	93
130	J-4(Burst1)	2230	<None>	0	2299.57	69
132	J-5	2235.77	<None>	0	2296.38	60
134	J-6	2242.61	<None>	0	2291.41	49
136	J-7	2232.01	<None>	0	2285.63	54
138	J-8	2254.16	<None>	0	2275.28	21
141	J-9	2258.76	<None>	0	2267.72	9
143	J-10	2263.54	<None>	0	2265.32	2
146	J-11	2238.92	<None>	0	2254.84	16
148	J-12	2175.44	<None>	0	2224.59	49
150	J-13	2105.28	<None>	0	2186.48	81
52	J-14	2063.41	<None>	0	2151.53	88
153	J-15	2022.87	<None>	0	2125.9	103
155	J-16	2012.87	<None>	0	2107.54	94
63	J-17	2006.09	<None>	0	2083.7	77
159	J-18	2003.37	<None>	0	2064.15	61
161	J-19	2009.1	<None>	0	2031.7	23
163	J-20(Burst3)	1921.61	<None>	0	2012.11	90
85	J-21	1969.5	<None>	0	1989.94	20
167	J-22	1954.6	<None>	0	1978.46	24
169	J-23	1945.39	<None>	0	1970.06	25
171	J-24	1937.49	<None>	0	1956.63	19
176	J-25	1916.91	Zone - 1	0	1927.05	10
178	J-26	1900.43	Zone - 1	0	1912.64	12
180	J-27	1873.72	Zone -	0	1900.79	27

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			1			
183	J-28	1923.7	Zone - 2	0	1938.37	15
185	J-29	1919.35	Zone - 2	0	1934.1	15
223	J-30	1887.07	Zone - 2	0	1927.7	41
225	J-31	1856.79	Zone - 2	0	1921.82	65
227	J-32	1833.21	Zone - 2	0	1915.61	82
242	J-33	1813.35	Zone - 2	0	1909.36	96
244	J-34	1799.14	Zone - 2	0	1905.53	106
246	J-35	1770.98	Zone - 2	0	1899.71	128
68	J-36	1754.75	<None>	0	1893.33	138
88	J-37	1753.08	Zone - 2	0	1879.52	126
90	J-38	1740.75	Zone - 2	0	1870.35	129
93	J-39	1730.26	Zone - 1	0	1861.81	131
94	J-40	1722.02	Zone - 2	0	1847.02	125
78	J-41	1719.4	Zone - 2	0	1844.45	125
87	J-42	1708.49	Zone - 2	0	1842.25	133
84	J-43	1706.31	Zone - 2	0	1840.78	134
83	J-44	1704.26	Zone - 2	0	1839.71	135
82	J-45	1706.54	Zone - 2	0	1838.41	132
258	J-46	1721.93	Zone - 2	0	1836.87	115
260	J-47	1761.78	Zone - 2	0	1833.02	71
74	J-48	1998.6	<None>	1.1	2082.13	83
96	J-49	1960.42	<None>	1.1	1988.04	28
544	J-50	1929.6	<None>	1.1	1954.2	25
188	J-51	1861.12	Zone - 1	0	1879.37	18

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546	J-52	1854.09	Zone - 1	1.1	1879.29	25
32	J-53	1851.32	Zone - 1	1.1	1879.12	28
71	J-54	1847.14	Zone - 1	1.1	1878.76	32
72	J-55	1838.61	Zone - 1	0	1878.26	40
73	J-56	1827.54	Zone - 1	1.1	1877.92	50
69	J-57	1830.18	Zone - 1	1.1	1877.75	47
75	J-58	1826.51	Zone - 1	0	1877.63	51
76	J-59	1833.44	Zone - 1	0	1877.5	44
294	J-60	1819.89	Zone - 1	1.1	1877.34	57
296	J-61	1806.89	Zone - 1	0	1877.27	70
77	J-62	1813.15	Zone - 1	0	1877.2	64
299	J-63	1780.84	Zone - 1	1.1	1877.14	96
301	J-64	1763.34	Zone - 1	0	1877.09	114
323	J-65	1754.32	Zone - 1	1.1	1877.04	122
328	J-66	1798.42	Zone - 1	1.1	1877.25	79
326	J-67	1811.38	Zone - 1	1.1	1877.5	66
320	J-68	1818.2	Zone - 1	1.1	1877.53	59
318	J-69	1818.45	Zone - 1	1.1	1878.45	60
43	J-70	1806.81	Zone - 1	1.1	1878.1	71
44	J-71	1806.16	Zone - 1	1.1	1877.76	71
339	J-72	1776.77	Zone - 1	1.1	1876.53	100
67	J-73	1774.74	Zone - 1	1.1	1876.48	102
313	J-74	1778.54	Zone - 1	0	1875.89	97

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653	J-75	1782.56	Zone - 1	0	1875.17	92
655	J-76	1778.02	Zone - 1	1.1	1874.53	96
306	J-77	1776.65	Zone - 1	0	1876.51	100
304	J-78	1764.07	Zone - 1	1.1	1876.54	112
565	J-79	1801.02	Zone - 1	1.1	1877.35	76
563	J-80	1805.75	Zone - 1	0	1877.16	71
560	J-81	1802.27	Zone - 1	1.1	1877.08	75
192	J-82	1855.65	Zone - 1	1.1	1878.74	23
33	J-83	1853.58	Zone - 1	1.1	1877.77	24
568	J-84	1798.71	Zone - 1	0	1876.53	78
571	J-85	1798.72	Zone - 1	1.1	1876.31	77
39	J-86	1783.77	Zone - 1	1.1	1872.36	88
40	J-87	1786.07	Zone - 1	1.1	1869.85	84
45	J-88	1797.08	Zone - 1	1.1	1869.17	72
47	J-89	1871.97	Zone - 1	1.1	1876.86	5
265	J-90	1826.66	Zone - 1	0	1876.79	50
46	J-91	1812.63	Zone - 1	1.1	1876.67	64
271	J-92	1813.18	Zone - 1	1.1	1876.43	63
576	J-93	1798.68	Zone - 1	0	1875.97	77
578	J-94	1795.36	Zone - 1	1.1	1875.72	80
580	J-95	1800.16	Zone - 1	0	1874.04	74
585	J-96	1832.77	Zone - 1	1.1	1869.75	37
587	J-97	1832.32	Zone - 1	0	1869.29	37

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589	J-98	1864.9	Zone - 1	0	1868.95	4
591	J-99	1815.54	Zone - 1	1.1	1868.69	53
593	J-100	1798.77	Zone - 1	0	1869.25	70
600	J-101	1805.43	Zone - 1	0	1868.45	63
602	J-102	1821.45	Zone - 1	0	1867.79	46
268	J-103	1815.3	Zone - 1	0	1876.2	61
48	J-104	1816.91	Zone - 1	1.1	1875.86	59
276	J-105	1811.76	Zone - 1	0	1875.8	64
278	J-106	1809.27	Zone - 1	1.1	1875.68	66
610	J-107	1831.72	Zone - 1	0	1866.43	35
612	J-108	1857.73	Zone - 1	1.1	1866.17	8
614	J-109	1841.44	Zone - 1	0	1864.68	23
616	J-110	1849.45	Zone - 1	0	1863.22	14
618	J-111	1842.18	Zone - 1	0	1861.61	19
626	J-112	1856.53	Zone - 1	1.1	1860.66	4
628	J-113	1850.69	Zone - 1	0	1860.57	10
630	J-114	1842.3	Zone - 1	1.1	1860.46	18
632	J-115	1835.18	Zone - 1	0	1860.89	26
637	J-116	1816.4	Zone - 1	1.1	1848.98	33
639	J-117	1818.11	Zone - 1	0	1840.58	22
641	J-118	1812.77	Zone - 1	1.1	1828.61	16
643	J-119	1810.91	Zone - 1	1.1	1820.93	10
646	J-120	1800.88	Zone - 1	0	1819.22	18

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648	J-121	1780.55	Zone - 1	0	1817.44	37
650	J-122	1759.15	Zone - 1	1.1	1815.44	56
396	J-123	1804.06	Zone - 2	0	1823.04	19
398	J-124	1811.5	Zone - 2	0	1822.39	11
400	J-125(Burst7)	1771	Zone - 2	0	1820.16	49
684	J-126	1777.57	Zone - 2	0	1819.64	42
660	J-127	1780.1	Zone - 2	0	1818.92	39
662	J-128	1763.55	Zone - 2	0	1818.38	55
664	J-129	1752.3	Zone - 2	0	1817.97	66
666	J-130	1770.22	Zone - 2	1.3	1817.43	47
668	J-131	1803.33	Zone - 2	0	1817.37	14
678	J-132	1792.55	Zone - 2	1.3	1817.29	25
673	J-133	1758.06	Zone - 2	1.3	1817.3	59
675	J-134	1766.34	Zone - 2	0	1817.68	51
687	J-135	1797.83	Zone - 2	0	1818.31	20
689	J-136	1784.8	Zone - 2	0	1819.41	35
411	J-137	1727.5	Zone - 2	1.3	1816.36	89
81	J-138	1733	Zone - 2	1.3	1815.72	83
404	J-139	1708.63	Zone - 2	1.3	1818.24	109
402	J-140	1722.01	Zone - 2	0	1819.27	97
430	J-141	1705.54	Zone - 2	1.3	1817.77	112
729	J-142	1708.99	Zone - 2	1.3	1817.55	108
727	J-143	1723.82	Zone - 2	1.3	1814.97	91

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746	J-144	1728.41	Zone - 2	1.3	1814.13	86
721	J-145	1734.23	Zone - 2	1.3	1813.34	79
719	J-146	1750.4	Zone - 2	1.3	1809.2	59
717	J-147	1755.17	Zone - 2	1.3	1790.61	35
715	J-148	1757.7	Zone - 2	0	1786.47	29
708	J-149	1758.45	Zone - 2	1.3	1783.41	25
710	J-150	1762.66	Zone - 2	1.3	1781.53	19
706	J-151	1742.38	Zone - 2	1.3	1786.18	44
759	J-152	1729.8	Zone - 2	0	1806.85	77
704	J-153	1727.24	Zone - 2	1.3	1811.05	84
408	J-154	1726.03	Zone - 2	1.3	1814.59	88
765	J-155	1736.04	Zone - 2	0	1807.68	71
763	J-156	1737.89	Zone - 2	0	1802.43	64
756	J-157	1755.55	Zone - 2	1.3	1796.59	41
754	J-158	1763.3	Zone - 2	0	1792.99	30
752	J-159	1746	Zone - 2	1.3	1787.03	41
750	J-160	1775.65	Zone - 2	1.3	1785.74	10
723	J-161	1739.55	Zone - 2	1.3	1807.47	68
774	J-162	1735.32	Zone - 2	1.3	1807.63	72
776	J-163	1739.59	Zone - 2	0	1808.88	69
733	J-164	1725.86	Zone - 2	1.3	1812.92	87
737	J-165	1725.15	Zone - 2	0	1812.77	87
739	J-166	1718.17	Zone - 2	1.3	1812.58	94

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793	J-167	1718.79	Zone - 2	1.3	1816.93	98
418	J-168	1716.91	Zone - 2	1.3	1815.77	99
95	J- 169(Burst5)	1714	Zone - 2	1.3	1815.18	101
97	J-170	1776.1	Zone - 2	0	1814.85	39
92	J-171	1736.38	Zone - 2	1.3	1814.51	78
91	J- 172(Burst6)	1774	Zone - 2	1.3	1814.31	40
89	J-173	1782.62	Zone - 2	0	1814.26	32
770	J-174	1791.95	Zone - 2	0	1814.21	22
772	J-175	1799.77	Zone - 2	1.3	1814.16	14
466	J-176	1704.21	Zone - 2	0	1816.51	112
86	J-177(Burst 9)	1646	Zone - 2	0	1815.08	169
469	J-178	1719.73	Zone - 2	1.3	1813.27	93
471	J-179	1754.11	Zone - 2	0	1804.13	50
473	J-180	1757.92	Zone - 2	1.3	1794.98	37
425	J-181	1762.85	Zone - 2	0	1793.35	30
426	J-182	1750.4	Zone - 2	1.3	1790.58	40
432	J-183	1744.99	Zone - 2	1.2	1816.65	72
98	J-184	1703.29	Zone - 2	1.2	1815.16	112
108	J-185	1785.55	Zone - 2	1.2	1814.32	29
110	J- 186(Burst8)	1685	Zone - 2	1.2	1806.82	122
101	J-187	1775.43	Zone - 2	1.2	1798.35	23
102	J-188	1692.52	Zone - 2	1.2	1797.87	105
106	J-189	1702.73	Zone - 2	1.2	1806.52	104

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109	J-190	1694.17	Zone - 2	1.2	1803.6	109
103	J-191	1732.5	Zone - 2	1.2	1797.3	65
104	J-193	1717.47	Zone - 2	0	1795.26	78
783	J-194	1708.08	Zone - 2	1.2	1788.71	80
785	J-195	1706.56	Zone - 2	0	1788.37	82
441	J-196	1696.58	Zone - 2	1.2	1787.69	91
788	J-197	1690.17	Zone - 2	1.2	1789	99
790	J-198	1670.17	Zone - 2	0	1796.09	126
443	J-199	1675.92	Zone - 2	1.2	1799.1	123
445	J-200	1719.76	Zone - 2	1.2	1800.26	80
447	J-201	1760.58	Zone - 2	1.2	1802.7	42
449	J-202	1714.06	Zone - 2	0	1805.65	91
455	J-203	1682.09	Zone - 2	1.2	1791.91	110
457	J-204	1678.94	Zone - 2	0	1783.81	105
99	J-205	1655.58	Zone - 2	1.2	1777.52	122
460	J-206	1648.43	Zone - 2	1.2	1775.68	127
462	J-207	1655.26	Zone - 2	1.2	1776.26	121
100	J-208	1665.3	Zone - 2	1.2	1781.56	116
373	J-209	1793.62	Zone - 1	1.1	1859.92	66
371	J-210	1771.78	Zone - 1	0	1854.38	82
369	J-211	1784.91	Zone - 1	0	1851.79	67
367	J-212	1772.31	Zone - 1	1.1	1848.04	76
375	J-213	1760.43	Zone - 1	1.1	1840.33	80

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64	J-214	1750.87	Zone - 1	0	1836.05	85
799	J-215	1742.83	Zone - 1	0	1834.34	91
801	J-216	1744.51	Zone - 1	0	1831.75	87
809	J-217	1743.13	Zone - 1	1.1	1830.49	87
811	J-218	1805.03	Zone - 1	0	1875.18	70
813	J-219	1786.09	Zone - 1	1.1	1870.79	85
815	J-220	1769.7	Zone - 1	1.1	1870.38	100
817	J-221	1756.71	Zone - 1	0	1874.62	118
190	J-222	1860.64	Zone - 1	1.1	1879.26	19
819	J-223	1833.24	Zone - 1	1.1	1878.43	45
821	J-224	1821.67	Zone - 1	1.1	1878.09	56
604	J-A1	1843	Zone - 1	1.1	1866.58	24
620	J-A2	1821.07	Zone - 1	1.1	1863.96	43
622	J-A3	1840.91	Zone - 1	0	1863.2	22
634	J-A4	1827.12	Zone - 1	1.1	1861.38	34
832	J-Burst2	2255.29	<None>	0	2263.98	9
829	J-Burst4	1811	Zone - 1	1.1	1877.3	66

Pump report

Label	Elevation (m)	Pump Definition	Status (Initial)	Hydraulic Grade (Suction) (m)	Hydraulic Grade (Discharge) (m)	Flow (Total) (L/s)	Pump Head (m)
PMP-1	2218.92	Pump Definition - 1	On	2216.27	2310.75	88.391	94.48
PMP-2	2214.74	Pump Definition - 2	On	2215.37	2302.71	22.606	87.34

Reservoir Report

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Label	Elevation (m)	Zone	Flow (Out net) (L/s)	Hydraulic Grade (m)
R-1(BORE HOLE 1)	2219.27	<None>	88.391	2219.27
R-2(BORE HOLE 2)	2215.55	<None>	22.606	2215.55

Tank Report

Label	Zone	Elevation (Base) (m)	Elevation (Minimum) (m)	Elevation (Initial) (m)	Elevation (Maximum) (m)
Pressure break	<None>	2260	2260.3	2262.4	2262.6
T-1 (RESERVOIR 1)	<None>	1938	1938.4	1943.5	1943.6
T-2(RESERVOIR 2)	Zone - 1	1875	1875.3	1879.6	1879.7
T-3(RESERVOIR 3)	Zone - 2	1818	1818.47	1823.62	1823.72

Appendix D: Calibration and validation works for simulated pressure at where pipe failure was appeared and not appear

By using C-Factors					
	D	C	L	Q	Pressure(mH2O)
(B1)	0.25	130	2131	0.133	69
	0.25	120	2131	0.133	75
	0.25	110	2131	0.133	81
	0.25	100	2131	0.133	89
	0.25	90	2131	0.133	99
(B2)	D	C	L	Q	Pressure(mH2O)
	0.25	130	2131	0.133	9
	0.25	120	2131	0.133	9
	0.25	110	2131	0.133	9
	0.25	100	2131	0.133	10
(B3)	D	C	L	Q	Pressure(mH2O)
	0.3	130	3201	0.133	86
	0.3	120	3201	0.133	91
	0.3	110	3201	0.133	92
	0.3	100	3201	0.133	90

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	0.3	140	3201	0.133	91
(B4)	D	C	L	Q	Pressure(mH2O)
	0.15	130	726	0.012	66
	0.15	120	726	0.012	66
	0.15	110	726	0.012	66
	0.15	100	726	0.012	66
	0.15	140	726	0.012	66
(B5)	D	C	L	Q	Pressure(mH2O)
	100	130	726	0.012	101
	100	120	726	0.012	101
	100	110	726	0.012	100
	100	100	726	0.012	100
	100	140	726	0.012	101
(B6)	D	C	L	Q	Pressure(mH2O)
	100	130	726	0.012	40
	100	120	726	0.012	40
	100	110	726	0.012	39
	100	100	726	0.012	39
	100	140	726	0.012	41
(B7)	D	C	L	Q	Pressure(mH2O)
	250	130	440	0.012	49
	250	120	440	0.012	49
	250	110	440	0.012	48
	250	100	440	0.012	48
	250	140	440	0.012	47
(B8)	D	C	L	Q	Pressure(mH2O)
	80	130	783	0.012	122
	80	120	783	0.012	120
	80	110	783	0.012	119
	80	100	783	0.012	117
	80	140	783	0.012	122
(B9)	D	C	L	Q	Pressure(mH2O)
	80	130	433	0.012	169
	80	120	433	0.012	168
	80	110	433	0.012	168
	80	100	433	0.012	167
	80	140	433	0.012	169

By using Pipe size (diameter)					
(B1)	D	C	L	Q	Pressure(mH2O)
	0.25	130	2131	0.133	69

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	0.2	130	2131	0.133	124
	150	130	2131	0.133	243
	100	130	2131	0.133	359
	300	130	2131	0.133	49
(B2)	D	C	L	Q	Pressure(mH2O)
	0.25	130	2131	0.133	9
	0.2	130	2131	0.133	11
	150	130	2131	0.133	16
	100	130	2131	0.133	21
	300	130	2131	0.133	8
(B3)	D	C	L	Q	Pressure(mH2O)
	0.3	130	3201	0.133	86
	0.25	130	3201	0.133	91
	0.2	130	3201	0.133	90
	0.15	130	3201	0.133	89
	0.1	130	3201	0.133	85
(B4)	D	C	L	Q	Pressure(mH2O)
	0.3	130	726	0.012	67
	0.25	130	726	0.012	67
	0.2	130	726	0.012	66
	0.15	130	726	0.012	66
	0.1	130	726	0.012	65
(B5)	D	C	L	Q	Pressure(mH2O)
	0.2	130	726	0.012	103
	0.15	130	726	0.012	102
	0.1	130	726	0.012	100
	0.9	130	726	0.012	100
	0.75	130	726	0.012	96
(B6)	D	C	L	Q	Pressure(mH2O)
	0.2	130	726	0.012	43
	0.15	130	726	0.012	42
	0.1	130	726	0.012	40
	0.9	130	726	0.012	38
	0.75	130	726	0.012	32
(B7)	D	C	L	Q	Pressure(mH2O)
	0.3	130	440	0.012	50
	0.25	130	440	0.012	49
	0.2	130	440	0.012	49
	0.15	130	440	0.012	45
	0.1	130	440	0.012	25
(B8)	D	C	L	Q	Pressure(mH2O)

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	0.1	130	783	0.012	126
	0.8	130	783	0.012	122
	0.65	130	783	0.012	111
	0.5	130	783	0.012	82
	0.4	130	783	0.012	38
(B9)	D	C	L	Q	Pressure(mH2O)
	0.1	130	433	0.012	170
	0.8	130	433	0.012	169
	0.65	130	433	0.012	164
	0.5	130	433	0.012	147
	0.4	130	433	0.012	99

Label	Types of pipe	Diameter (m)	PN(m)	Measured pressure(m)	Simulated pressure (mH2O)
J_3	DCI	0.35	160	88	93
	DCI	0.3	160	88	93
	DCI	0.25	160	88	93
	DCI	0.2	160	88	93
	DCI	0.15	160	88	90
	DCI	0.1	160	88	77
J_10	uPVC	0.35	100	6	1
	uPVC	0.3	100	6	1
	uPVC	0.25	100	6	2
	uPVC	0.2	100	6	4
	uPVC	0.15	100	6	12
	uPVC	0.1	100	6	32
J_15	uPVC	0.35	160	100	118
	uPVC	0.3	160	100	103
	uPVC	0.25	160	100	59
	uPVC	0.2	160	100	34
	uPVC	0.15	160	100	7
	uPVC	0.1	160	100	3
J_86	uPVC	0.25	160	85	92
	uPVC	0.2	160	85	91
	uPVC	0.15	160	85	88
	uPVC	0.1	160	85	68

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	uPVC	0.08	160	85	30
	uPVC	0.065	160	85	4
J_36	DCI	0.35	160	131	145
	DCI	0.3	160	131	143
	DCI	0.25	160	131	138
	DCI	0.2	160	131	127
	DCI	0.15	160	131	101
	DCI	0.1	160	131	70
J_154	HDPE	0.2	160	102	89
	HDPE	0.15	160	102	89
	HDPE	0.1	160	102	88
	HDPE	0.08	160	102	87
	HDPE	0.065	160	102	83
	HDPE	0.05	160	102	76
J_160	HDPE	0.15	160	19	10
	HDPE	0.1	160	19	10
	HDPE	0.08	160	19	10
	HDPE	0.065	160	19	10
	HDPE	0.05	160	19	10
	HDPE	0.04	160	19	9
J_210	GI	0.15	160	85	89
	GI	0.1	160	85	88
	GI	0.08	160	85	87
	GI	0.065	160	85	86
	GI	0.05	160	85	82
	GI	0.04	160	85	72
J_221	GI	0.15	160	110	120
	GI	0.1	160	110	120
	GI	0.08	160	110	119
	GI	0.065	160	110	119
	GI	0.05	160	110	119
	GI	0.04	160	110	118

Appendix E: During field measures of total pipe buried depth at frequently pipe burst




Appendix F: During field measures of total pipe buried depth at no pipe burst appeared



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Appendix G: PH of the Chiro town water supply


  
 Water Works Design and Supervision Enterprise Laboratory Service Sub Process  
 Water Quality Section  
 P.O. Box 2561  
 Addis Ababa

Tel. 251 - 116 - 18 55 16/61 45 01  
 Fax. 251 - 116 - 61 53 71/61 08 98  
 e-mail: w.w.d.s.e@waterworks.gov.et

**SELECTED PHYSIO CHEMICAL AND BACTERIOLOGICAL WATER ANALYSIS RESULTS**

Client/Project: CGC OVERSEAS CONSTRUCTION ETH. LTD

LOCATION	Well				WHO maximum allowable Concentration (mg/l)
DATE OF COLLECTION	Chiro				
DATE RECEIVED	24/11/2013				
	2/12/2013				
CLIENTS ID.NO.					
LAB.ID NO.	CH-BH-5				
Colour (app)	919/2006				
Turbidity (NTU)	-				-
Total Solids 105 °C (mg/l)	0.365				5.0
Total Dissolved Solid 105 °C (mg/l)	342				-
Electrical Conductivity (µS/cm)	539.00				1000.0
Ammonia (mg/l NH <sub>3</sub> )	7.26				6.5-8.5
Sodium (mg/l Na)	0.30				-
Potassium (mg/l K)	16.50				200.0
Total Hardness (mg/l Ca CO <sub>3</sub> )	1.10				-
Calcium (mg/l Ca)	278.00				500.0
Magnesium (mg/l Mg)	60.00				200.0
Total Iron (mg/l Fe)	18.72				150.0
Manganese (mg/l Mn)	0.04				0.3
Fluoride (mg/l F)	0.04				0.1
Chloride (mg/l Cl)	0.47				1.5
Nitrite (mg/l NO <sub>2</sub> )	8.19				250.0
Nitrate (mg/l NO <sub>3</sub> )	0.02				-
Alkalinity (mg/l CaCO <sub>3</sub> )	1.07				45.0
Carbonate (mg/l CO <sub>3</sub> )	280.00				-
Bicarbonate (mg/l HCO <sub>3</sub> )	Nil				-
Sulphate (mg/l SO <sub>4</sub> )	341.60				-
Phosphate (mg/l PO <sub>4</sub> )	10.42				400
Total Coliform Per 100 ml	0.36				-
Fecal Coliform Per 100 ml	-				-

REMARK:- The test result can be compared with the WHO maximum allowable concentration (mg/l) presented on the last column But it is difficulty to decide the suitability of water for drinking purpose by comparing the above parameters only. The water sample was collected and submitted to our laboratory by the client.

Processed & tested by *[Signature]* Date: 2/12/2013

Checked by *[Signature]* Date: 09/12/2013

Approved by *[Signature]* Date: 9/12/13

Source: Chiro Town Well completion report, 2013

Appendix H: During water pressure measures on the fields

